SIMULATION OF MICRO HYDRO POWER BASED ON RIVER CONFIGURATION AT RIVER UPSTREAM

NUR AZIRAH BINTI ABDUL RAHIM

BACHELOR OF MECHANICAL ENGINEERING

UNIVERSITI MALAYSIA PAHANG

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NUR AZIRAH BINTI ABDUL RAHIM

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I certify that the project entitled Simulation of Micro Hydro Power Based on Upstream River Configuration is written by Nur Azirah Binti Abdul Rahim. I have examined the final copy of this report and in my opinion, it is fully adequate in terms of language standard, and report formatting requirement for the award of the degree. I herewith recommend that it be accepted in partial fulfillment of the requirement for the degree of Bachelor of Mechanical Engineering.

MR. IDRIS BIN MAT SAHAT

Examiner Signature

SUPERVISOR'S DECLARATION

I hereby declare that I have checked this project and in my opinion, this project is adequate in terms of scope and quality for the award of degree of Bachelor of Mechanical Engineering.

Signature :

Name of Supervisor : MR IDRIS BIN MAT SAHAT

Position : LECTURER

Date : 20 JUNE 2013

STUDENT'S DECLARATION

I declare that this report entitled Simulation of Micro Hydro Power Based on Upstream River Configuration is my result of my own research except as stated in the references. The project has not been accepted for any degree and is not concurrently submitted for award of other degree.

Signature :

Name : NUR AZIRAH BINTI ABDUL RAHIM

ID Number : MA 09125

Date : 20 JUNE 2013

Dedicated to my parents.

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ABSTRACT

Micro hydro power is a reliable form of energy. Pelton and Turgo turbine are examples of turbine that can be applied to install Micro Hydro Power. The purpose of this paper is to determine the performance and efficiency of Micro Hydro Power at Panching Waterfall, to simulate the flow of upstream river configuration and to determine the suitable turbine to be installed at high head river. Small scale hydro power can be develop in rural areas for clean electrification. The velocity and flow rate of the waterfall is determined and applied to the analysis to identify the suitable turbine to be used. To obtain the results, simulation using ANSYS CFX is done. The solver can determine the output velocity and torque of the flow through the respective cup, and then theoretical results are determined using calculations. The efficiency of Pelton is 0.965 while Turgo is 0.969. The value of torque is determined from the simulation resuts. The value is 9.25 N.m for Pelton and 7.41 N.m for Turgo. The results are then compared with theoretical results which the value for Pelton is 1.4 N.m and 1.316 for Turgo. From these results, the power output is calculated and the values are 1487.5 and 1483.5 for Pelton and Turgo respectively. These results clearly show that Pelton Turbine is suitable for high head Micro Hydro Power. On the other hand, simulation results also shows that Pelton has higher power output than Turgo where the values are 1476 watt and 1465.5 watt respectively.

ABSTRAK

Kuasa mikro hydro adalah satu bentuk tenaga yang boleh diaplikasikan. Pelton dan Turgo turbin adalah contoh turbin yang boleh digunakan untuk kuasa mikro hidro.Laporan ini adalah untuk menentukan prestasi dan kecekapan kuasa mikro hidro di Air Terjun Panching, untuk mensimulasikan aliran konfigurasi hulu sungai dan untuk menentukan turbin yang sesuai untuk dipasang di sungai beraliran tinggi. Kuasa hidro Yyang kecil boleh dibangunkan di kawasan luar bandar bagi bekalan elektrik bersih. Halaju dan kadar aliran air terjun ditentukan dan digunakan untuk analisis untuk mengenal pasti turbin yang sesuai untuk digunakan. Simulasi menggunakan ANSYS CFX digunakan untuk mendapatkan data dan maklumat bagi aliran air . Penyelesai boleh menentukan kelajuan output dan tork aliran melalui cawan masing-masing, dan kemudian keputusan teori yang menentukan menggunakan pengiraan. Kecekapan Pelton ialah 0.965 manakala Turgo adalah 0,969. Nilai tork adalah menentukan dari resuts simulasi. Nilai adalah 9.25 Nm untuk Pelton dan 7.41 Nm untuk Turgo. Keputusan ini kemudiannya dibandingkan dengan keputusan teori yang mana nilai untuk Pelton ialah 1.4 Nm dan 1,316 untuk Turgo. Daripada keputusan ini, output kuasa dikira dan nilai masing-masing dan 1487,5 1483,5 untuk Pelton dan Turgo. Keputusan ini jelas menunjukkan bahawa Pelton turbin sesuai untuk kepala tinggi Micro Hydro Power. Keputusan ini juga selari dengan simulasi yang dilakukan dimana Pelton turbine Lebih tinggi daripada Turgo.

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LIST OF SYMBOLS

ω	Tangential Component
T	Torque
P	Power
k	Velocity Coefficient
v_1	Velocity at Inlet
U	Bucket Velocity
η	Efficiency
r	Velocity Relative to Bucket
$\dot{m}$	Mass Flow Rate

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

Hydro power produces electricity using natural flow of water. This is considered the most cost effective energy technology for rural electrification in potential areas. Micro hydro power is developing around the country in producing clean electrification. Performance of micro hydro power depends on the site more on the cost.

Hydropower systems use the energy in flowing water to produce electricity or mechanical energy. Although there are several ways to harness the moving water to produce energy, run-of-the-river systems, which do not require large storage reservoirs, are often used for micro hydropower systems. Turbines are commonly used today to power micro hydropower systems. The moving water strikes the turbine blades, much like a waterwheel, to spin a shaft. But turbines are more compact in relation to their energy output than waterwheels. They also have fewer gears and require less material for construction.

Micro hydro power generally produces up to 100kW of electricity. These amounts of electricity can provide electricity in an isolated home or small community. This application is suitable to be implemented in rural areas. In Malaysia, there are many locations that have potential for micro hydro power.

Geographical factors are important for hydropower. The higher head of a stream may produce more power. Sites with higher head are most desirable because they need less water, smaller pipe, fewer nozzles, and cost less to install, and fare better in low water years. The main obstacle of micro hydro power is costs. Many researched had been done to determine the higher performance of turbine with lower operating and maintenance cost.

1.2 PROBLEM STATEMENTS

Geographical factors play an important role in Micro Hydro Power Plant (MHPP). The height (head) of river, velocity of flow, sediment discharge, and rainfall and topology data differs in every place. These factors may affect the performance and efficiency of Micro Hydro Power. In rural areas such as places that are remote from other energy sources has very limited facility of having electricity for home users and other purpose. However different types of Micro Hydro Power differ in performance and efficiency. The effectiveness of Micro Hydro Power is affected by the flow of water.

1.3 RESEARCH OBJECTIVES

1.3.1 To simulate the flow of upstream river for different Micro Hydro Power

1.3.2 To determine the performance and efficiency of Micro Hydro Power

1.3.3 To determine suitable Micro Hydro turbine for high head flow

1.4 PROJECT SCOPES

1.4.1 The scope involve in this project focus on the upstream river configuration where the velocity, pressure and topology data is to be determined.

1.4.2 Simulation is conducted using ANSYS based on the data colle suitable Micro Hydro Power with higher performance.

1.4.3 From the results obtained, suitable MHP is determined to be used upstream river of higher head.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In this chapter, information about hydropower is discussed. The sources of the review are extracted from journals, articles, reference books and internet. The purpose of this section is to provide additional information and relevant facts based on past researches which related to this project.

2.2 ADVANTAGES OF MICRO HYDROPOWER

Micro hydro power is hydroelectric power that typically produces 100kw electricity using natural flow of water. Small scale hydro power is cost effective and very reliable in producing clean electricity generation. A stream or river is used to generate electricity. Hydropower produces continuous supply from the flow of river. It is proven that micro hydro power is more economical than solar and wind power. There are many advantages of small hydropower that are going to be mention in the following paragraph.

According to research made by The British Hydropower Association, small hydropower has efficiency of 70-90%, so far the best compared to wind and solar power.

Higher efficiency will improve the performance of electricity generation. The research also proved that high capacity factor of micro hydro power (typically >50%), compared with 10% for solar and 30% for wind. Furthermore, small hydro has high predictability depends on the rainfall patterns. The flow and velocity of rives changes slowly from day to day. These slow rate changes make the output of the hydro power changes gradually.

Small hydropower is a long lasting and robust technology. The system can be used as long as 50 years or sometimes more. Small hydro power also always follows the demand, during winter the output is maximum. This is a good correlation with demand. Small hydropower is environmental friendly where it does not affect the natural ecosystem. No reservoir required for micro hydro because it based on run-of-river system.

Small hydropower systems allow achieving self-sufficiency by using the best as possible the insufficient natural resource such as water, as a decentralized and low-cost of energy production. Hydropower is the most important energy source in what concerns no carbon dioxide, sulphur dioxide, nitrous oxides or any other type of air emissions and no solid or liquid wastes production. This system produces a cleaner energy system. It also saves the consumption of fossil, fuel and firewood (Ramos, H. et al).

2.3 PARAMETERS OF MICRO HYDRO POWER

2.3.1 Head

Head of flow is the vertical fall of water flow from higher to lower lever due to potential energy. For example river passes a waterfall. Head is an important parameter of hydropower. The head affect the flow rate of the flow. Head of flow can be determined by measuring the flow from the highest point to the lowest water drop as shown in figure 2.1. The unit of head is in meter (m). It is generally better to have more head than more flow (British Hydropower Association).

Figure 2.1: Head of Flow

Source: Panching Waterfall

Gross Head (H) is defined as the maximum level that is available for the vertical fall of water. The actual head seen by a turbine will be slightly less than the gross head. This is due to losses incurred when transferring in and out of the hydropower.

2.3.2 Flow Rate

Flow is the quantity of water moving past a given point over a set time period (expressed as volume in gallons per minute (gpm) or cubic meters per second (m3/s). More water falling through the turbine will produce more power. The amount of water available depends on the volume of water at the source. Power is also ‘directly proportional’ to river flow, or flow volume. The flow rate is the product of volume and area (A.Zubaidi, 2010).

2.3.3 Power and energy

The amount of power available from a micro hydro generator system is directly related to the flow rate, head and the force of gravity. Once we have determined the usable flow rate (the amount of flow we can divert for power generation) and the available head for our particular site, we can calculate the amount of electrical power we can expect to generate (Zubaidi.A, 2010). Power is calculated using the following equation:

$$P = \rho g H Q \qquad (2.2)$$

P= Power

ρ=density of water

g= gravitational constant (9.81 m^2/s)

H=head of flow

Q= Flow rate

2.4 TURBINE EFFICIENCY

Efficiency is defined as a level of performance that describes a process that uses the lowest amount of inputs to create the greatest amount of outputs**.** For hydropower, the efficiency and performance of the plant mainly depends on the types of turbine used. Turbine selection is depending on the scale of hydropower and the location to install the turbine. Efficiency is affected by the Head (H), flow rate (Q), density of water (ρ) and gravitational constant.

Comparison between few turbines is made to determine the higher performance turbine. An important point to note is that the Pelton and Kaplan turbines retain very high efficiencies when running below design flow; in contrast the efficiency of the Crossflow and Francis turbines falls away more sharply if run at below half their normal flow. Most fixed-pitch propeller turbines perform poorly except above 80% of full flow (British Hydropower Association, 2005).

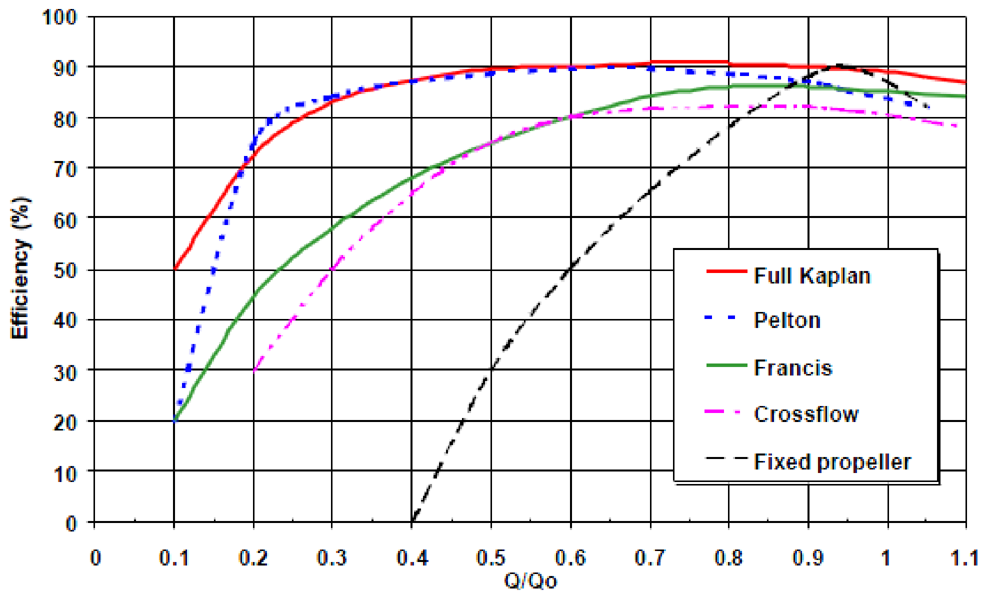


Figure 2.2: Turbine efficiency

Source: British Hydropower Association (2005)

The efficiency of turbine can be calculated using the following equation

$$P = \eta \text{ x } \rho \text{ x } g \text{ x } Hnet \text{ x } Q \qquad (2.3)$$

η = efficiency of turbine

ρ = density of water [kg/m3]

g = gravitational constant [m/s2]

Hnet = net head [m]

Q = volumetric flow rate [m3/s]

Table 2.1: Turbine Efficiency

Turbine	**Efficiency**
Pelton	0.90
Banki-Mitchell	0.87
Turgo	0.85
Francis	0.90
Kaplan	0.90

Source: Johnson.V (2008)

2.5 TURBINE SELECTION FOR MICRO HYDRO POWER

2.5.1 Pelton Turbine Designation Properties

The Pelton turbine consists of a wheel with a series of split buckets set around its rim a high-velocity jet of water is directed tangentially at the wheel. The jet hits each bucket and is split into half, so that each halves is turned and directed back almost through 180^o.Almost all the energy of the water goes into propelling the bucket and the directed water falls into a discharge channel below (O Paish, 2002).

There are many research proved that Pelton turbine is suitable to be apply in Micro Hydro Power over a relatively wide range head and flow conditions when compared to other turbine categories and is suitable for many medium and high head sites. There are many design of Pelton turbine in order to suits the condition of the flow. For micro hydro power upstream configuration, Pelton turbine is suitable to be used because of its characteristics. Pelton runners are subject to a combination of stresses caused by centrifugal force and cyclic loads. The centrifugal force is induced by the by the fast rotating body and is related to the runner speed and mass (G.Gilkes et al, 2003)

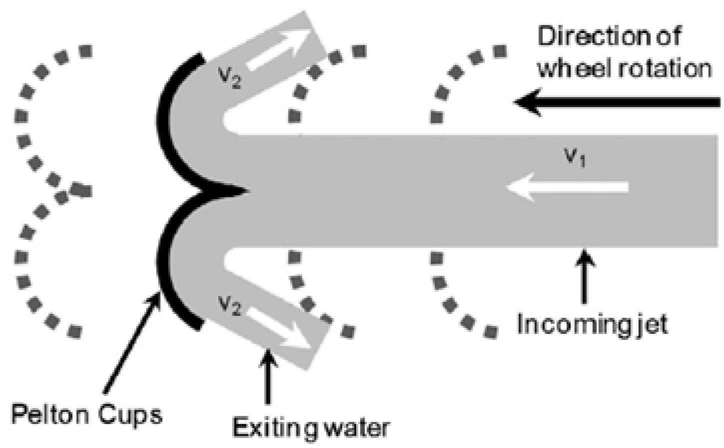


Figure 2.3: Pelton Turbine Cup

Source: S.J. Williamson (2012)

2.5.2 EFG Interlocking Runner Buckets

The method is based on a forging technique to produce buckets that include a patented interlocking clamping system, which link together the buckets to form the runner. Individual buckets can then be individually removed for repair or maintenance. After forging, the buckets are individually CNC machined to improve the surface finish and complete the required tolerances (G.Gilkes et al, 2003).

Figure 2.4: EFG Interlocking Runner Buckets

Source: G.Gilkes et al (2003)

For a Pelton runner, there are always be losses due to many surrounding effect. So the efficiency, η of turbine is set to 0.9. The diameter of nozzle can be determined from the following equation:

$$C = \sqrt{2gH} \qquad (2.4)$$

$$d_s = \sqrt{\frac{4Q}{Z\pi C}} \qquad (2.5)$$

where:

Q= Flow rate

z= Number of nozzles

H= head

The diameter of runner can be determined from the following

$D=10.d_s \quad H_n<500$ m

$D= 15.d_s \quad H_{n=}1300$m

Source: Design of Pelton Turbine Powerpoint Slides

The theoretical maximum power achievable by a Pelton turbine occurs when the wheel rotates at the following equation when the bucket moves at half the speed of the water jet (Yunus A.C,2006, pg 811).

$$W = \frac{V_J}{2r} \tag{2.6}$$

2.5.3 Turgo Turbine Design Consideration

For high head micro hydro power, impulse turbine is more preferred to be used rather than reaction turbine which is suitable for low head flow. According to S.J. Williamson, Turgo turbines were invented and patented in 1920 by Gilbert Gilkes Ltd (as cited in Gibson AH, 1948). The author also mentioned that, the differences of Turgo and Pelton turbines are the angle of incoming water jet is different. In Turgo turbines the jet enters and exits the wheel plane at an acute angle whereas in Pelton turbines the jet remains in the same wheel plane. Therefore, the water in a Turgo turbine exits from the bottom of the wheel and does not interfere with the incoming jet.

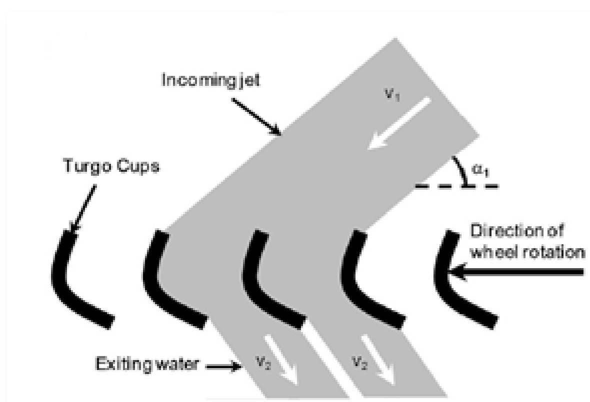


Figure 2.6: Torque generation mechanism of Turgo turbine

Source: S.J. Williamson (2012)

A Turgo turbine requires a penstock, nozzle and turbine wheel also known as disc. The following assumptions are made to act as a controlled for the experiment. All of the flow impacts with the cup in the parallel section. There is no radial flow within the cup, the incoming jet is not impinged by the exiting water or by the incoming cup, and there are no losses due to non-ideal entry conditions. Frictional velocity losses inside the cup are 5% (S.J. Williamson, 2012).

The velocity v_1 of the flow falling through a head H leaving the nozzle can be calculated by

$$V_1 = k\sqrt{2gH} \qquad (2.7)$$

and the continuity equation is

$$Q = \frac{V_1(\prod {D_J}^2)}{4} \qquad (2.8)$$

where:

k = loss factor from the nozzle

g= gravitational force

H =head

Q= flow rate

D_j= jet diameter

Therefore for a constant jet diameter, as the head increases the flow rate also increases. As the jet impacts the cup, it splits into two components and exits through the top and bottom of the cup (S.J. Williamson, 2012). This concepts increase the efficiency of the turbine.

Turgo turbine can handle significantly higher water flow rates. Turgo turbine is a low cost turbine where the runner is less expensive compared to Pelton. Furthermore, it doesn't need an airtight housing like the Francis. Moreover, it has higher specific speed and can handle a greater flow than the same diameter Pelton wheel, leading to reduced generator and installation cost (Bryan R.C, 2012).

Figure 2.7: 3D model of Turgo cups attached to wheel to form turbine disc

Source: S.J. Williamson (2012)

2.6 MICRO HYDRO POWER POTENTIAL IN RURAL AREAS

Hydropower, large and small, is by far the most important of the ‘renewable’ for electrical power production. World Hydropower Atlas 2000, published by the International Journal of Hydropower and Dams, reported that the world’s technically feasible hydro potential is estimated at 14370TWh/year, which equates to 100 per cent of today’s global electricity demand (O Paish, 2002).

Many rural areas in Malaysia have no access to electricity, which may lead to lack of socio economic development. Majority of electrical supply in Malaysia is produces by Tenaga Nasional Berhad (TNB). The total energy supplied for electricity generation is constituted by fossil fuel. Burning of fossil fuel will not last forever and it is damaging the environment and affecting the climate through the emission of greenhouse gases. Micro hydro power is the best solution to overcome this problem as it does not require dams and weirs. Furthermore, the impact to environment is very small.

Water is the only force running the plant and no fuel like diesel is needed as input. In areas that have flowing water such as river, waterfall and stream, there are potential of having micro hydro power in the area (Sundqvist,E et al, 2006). In Malaysia, the weather and geographical factors must be examined first before installing micro hydro power in that certain location.

The feasibility study of a hydroelectric plant, even if small, needs information on the available water resources in order to assess the potential energy production of the plant. The flow duration curve of the stream is derived from the data published in the Italian Annals of hydrology (A. Renata, 2011).

2.6.1 Cost and Economical Factors

A major barrier to start a small scale hydro power project is an understanding of how much the scheme will cost. Is the project worth with the outcome comparing to cost. Empirical formulae to estimate the cost of electro-mechanical equipment and the costs of different types of turbines were developed through statistical analysis of cost data obtained from a range of turbine manufacturers (G.A. Aggidis, 2010).

Consideration also must be made on the maintenance of the turbine, maintenance should be done regularly in order to preserved the performance of the turbine and also reduce repairing cost in future. So, it is important to plan and study the cost and financial of micro hydro power before installation. The capital costs of hydro plant installation are high, operating and maintenance costs are low, which means that a large proportion of the project's overall budget will be spent at the development stage. It is therefore important to balance the cost installation against the magnitude and speed of energy output to determine whether the project is worth pursuing. Then, plan the subsequent budget. Cost estimation is made according to many factors including the geographical factors, materials used and labor work. The following table shows the cost range for 100 kW small hydro installations:

Table 2.2: Cost for 100 kW hydropower

Tasks	Low Head	High Head
Machinery	60-120	30-60
Civil works	30-100	30-80
Electrical works	15-30	15-30
External costs	10-30	10-30
Total	115-280	85-200

Source: The British Hydropower Association

A researched made in Tanzania clarifies that the active financier for remote areas are the government, international donors and religious societies. Rural electrification projects have the reputation of being both unprofitable and of high risks. Recently studied small hydropower potentials of Sunda Fall, Igamba Falls, Nzovwe and Pinyinyi, in the rural electrification master plan study of 2005 were found to be financially unviable even at the highest tariff condition. This is the main reason why so few small hydro projects have been built, as well as why the government in collaboration with donors and nonprofit organizations remain the main participants in rural electrification.

A research had also been made in Lao PDR, Laos. This rural area is one of the poorest countries in the world. The number of households with access to electricity has increased from 16% in 1995 to 47% in 2005(as cited in Matayakham, 2006). The Government of Lao PDR (GoL) aims to electrify 70 % of all households until 2010 and 90% until 2020 (Araki 2005, Mataykham 2006). Since extension of the national grid is very expensive the GoL believes that renewable energy sources are necessary for rural electrification (Sundqvist.E, 2006).

Table 2.3: Source of Electricity Production

Source of Electricity Production	Installed Capacity (MW)	Percentage of Total Electricity Production
Major Hydropower Plants	624	96.29
Small Hydropower Plant	6.04	0.93
Diesel	17.29	2.68
PV Solar	0.156	0.026
Total	648	100

Source: Sundqvist.E (2006)

2.7 CHARACTERISTICS OF TURBINE

2.7.1 Material Selection of Turbine

The choice of material is made based on the scale of hydropower and the velocity of water flow to the turbine. The material affects the mass of the turbine, so if the scale of turbine is small, high mass is not suitable to be used. This will lead to slow rotation of the turbine. Material selection is important and need to be chosen carefully in order to reduce the cost of fabrication of the turbine.

The material of manifold, nozzle, penstock, runner and turbine is different. It is based on the performance of the parts. Material must be strong and can withstand high pressure of water. Environmental factors also must take into account for the selection, for example hot sun, rain, and dry season. These factors may affect the turbine, so suitable material must be used.

There are several materials can be used for the turbine, for example bronze, steel alloy with nickel, chromium and stainless steel. These materials have it own characteristics. As for steel allow with nickel, it is valuable in many industries for their resistance to corrosion and their retention of strength as well as other mechanical properties in extreme temperatures (nickelalloy.net).

According to Jostedal Power Plant, Norway, the material for turbine is structural steel, High Strength Micro Alloy (HSMA), and heat treatment steel is used for their manufacturing of hydro power turbine.

Figure 2.8: Pelton Turbine Runner

Source: Jostedal Power Plant, Norway

General corrosion resistance of nickel alloy is the ability of a metal to avoid surface damage which can impair the aesthetic appearance but does not usually affect the structural of the metal. Nickel alloys resist surface damage as well as erosion and abrasion. This property makes nickel alloys useful in industries where erosion or abrasion of a material could damage product or where an aesthetic appearance is necessary (nickel-alloy.net).

2.7.2 Dimension of Turbine

Basically, Pelton turbine for micro hydro power is smaller in size compared to hydro power. The dimension and size of cup, runner and nozzle has its calculation to determine the parameter. This is to analyze the performance of the turbine analytically.

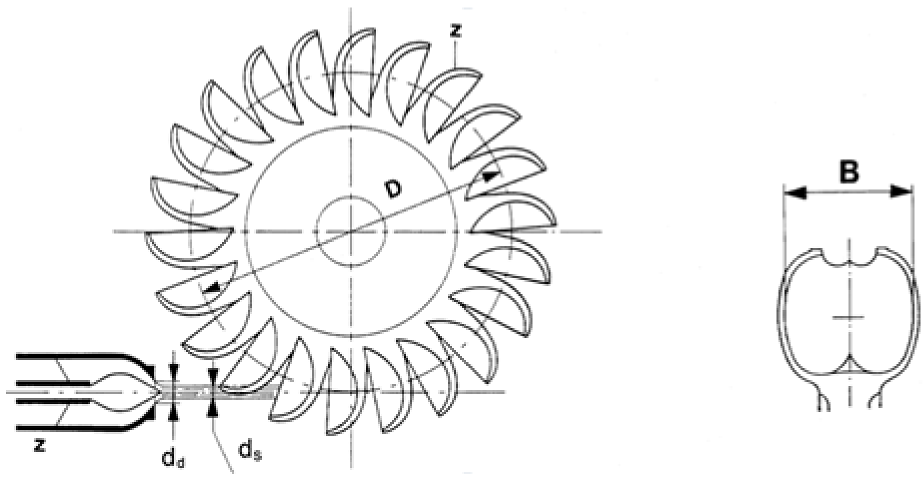


Figure 2.9: Main Dimension of Pelton Turbine

Source: Design of Turbine Powerpoint Slides

Determination should be made in every parts of turbine including the Pelton runner, size of buckets, number of nozzles, and number of buckets. This information can be used to calculate the speed of rotation of the turbine. It is also can be applied to Turgo turbine as the turbine is the same to Pelton turbine, the difference is the cup of turbine.

2.8 FLOW DATA

Flow of data for high head flow range 75-100m is determined by using calculation and existing research which is relevant for this head. Panching Waterfall is linked to Sungai Pandan River. These areas are under the surveillance of Jabatan Perhutanan Negeri Pahang. On the other hand, Jabatan Pengairan Dan Saliran Negeri (JPS) are in charge of the flow of river in Pahang. Unfortunately, the flow of river of Panching Waterfall does not exist because it is a recreational area which does not require any flow data to be examined. They are only particular about public safety, so the important data is the height of the river.

These data is important to determine the speed of rotation of turbine and the efficiency of turbine. Data that are constant such as density and viscosity is used as well. Flow data such as flow rate, velocity, area, and mass flow rate is collected from existing source. In figure 2.10, the value of velocity and head is illustrated for water flow. The chart based on air density 1.205 kg/m^3 and water density 1000 kg/m^3.

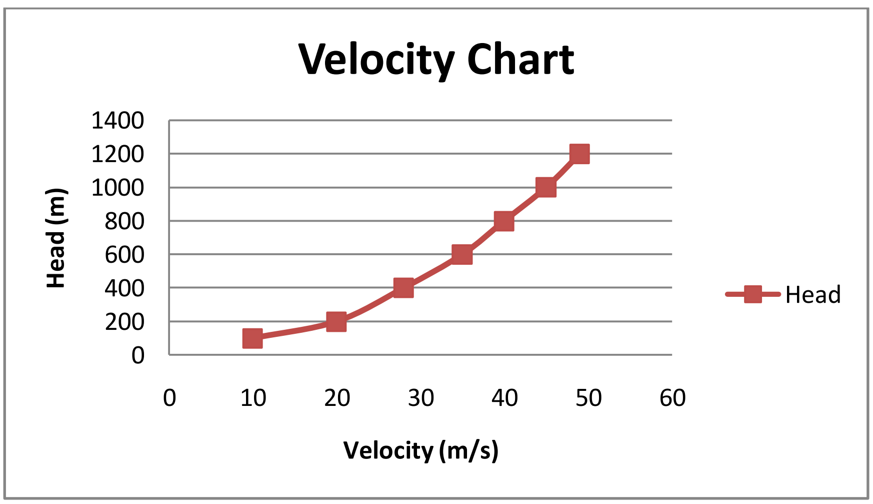


Figure 2.10: Velocity and Head chart

Source: pumpfundamentals.com

The density of water is 1000kg/m^3, and viscosity is $1x10^{-3}$ kg/(m.s).Nozzle diameter to be used is 0.01m.Volume flow rate is 0.785 m^3/s and velocity of water at the outlet is 10.18m/s. From the volume flow rate, the value of mass flow rate can be calculated using the following equation

Volume flow rate= VA (2.13)

V=velocity

A=area

Mass flow rate= ρVA (2.14)

ρ= density of water

V= velocity

A=area

Table 2.4: Micro Hydro Installation Sizing

Power vs. static head for 2" pipe, (4) optimum nozzle dia.

Q (Usgpm)	static head (ft)	pipe dia (in)	no. of nozzles	nozzle dia. (in)	HF (ft)	f coef.
22	25	2	4	0.25	5.94	0.025
31	50	2	4	0.25	11.19	0.024
38	75	2	4	0.25	16.36	0.023
44	100	2	4	0.25	21.54	0.023
54	150	2	4	0.25	31.69	0.022

Reynolds no.	pipe velocity (ft/s)	nozzle velocity based on friction (ft/s)	single nozzle velocity (ft/s)	water jet power (1) nozzle (W)	power at turbine wheel (W)
34806	2.25	35.02	35.95	21	37
49044	3.17	49.97	50.65	58	105
60119	3.88	61.42	62.09	107	193
69612	4.49	71.05	71.9	167	300
85432	5.51	87.25	88.24	308	554

Source: pumpfundamentals.com

Table 2.4 describes the Micro Hydro installation sizing where the value of nozzle diameter and pipe diameter was calculated to be applied with certain amount of speed of water. From the table, the value of average friction coefficient is taken which is 0.02. The pipe diameter is 0.01 m and the nozzle diameter is calculated in Chapter 4.

CHAPTER 3

METHODOLOGY

3.1 METHODOLOGY FLOW CHART

The methodology flow chart is constructed to show the process of tasks throughout the project. It is constructed based on the scope of the project in order to achieve the objectives. It also acts as a guideline to make sure that the project is on track. The terminology of the project is shown in the flow chart below.

The flow chart consists of literature review which mainly a study of research that had been done before. Journals, books, thesis and the internet are the main source of literature review. Data collection is also extracted from the literature review. Data is also collected from site visit at Panching waterfall. Data collection is the most important part of this project where the existing turbine is used to do a simulation.

Figure 3.1: Panching Waterfall

Site visit also is a source of data collection. From the site visit, the geographical factors of the waterfall were observed. Furthermore, the value of head and flow rate was determined from the site visit to Sungai Pandan River. From the observation, the area has the potential of Micro Hydro Power generation where there are suitable sites to install the turbine. The following figures describe the waterfall structure.

Generally, Panching Waterfall is a recreational area where many people come here for picnic. Panching Waterfall is handled by Jabatan Perhutanan Negeri Pahang. This area is suitable for micro hydro power because it can supply electricity to the surrounding area which only supplies electricity in small amount.

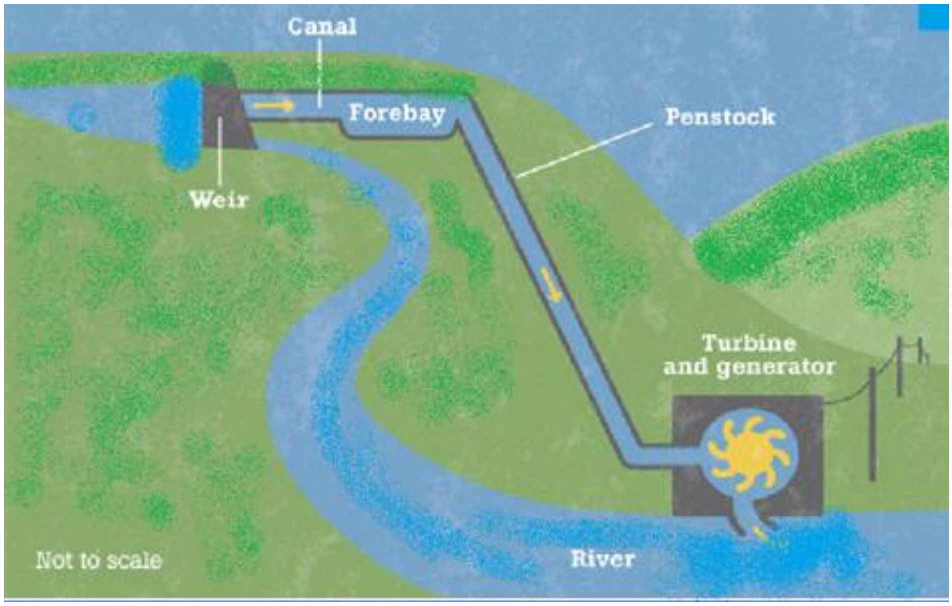
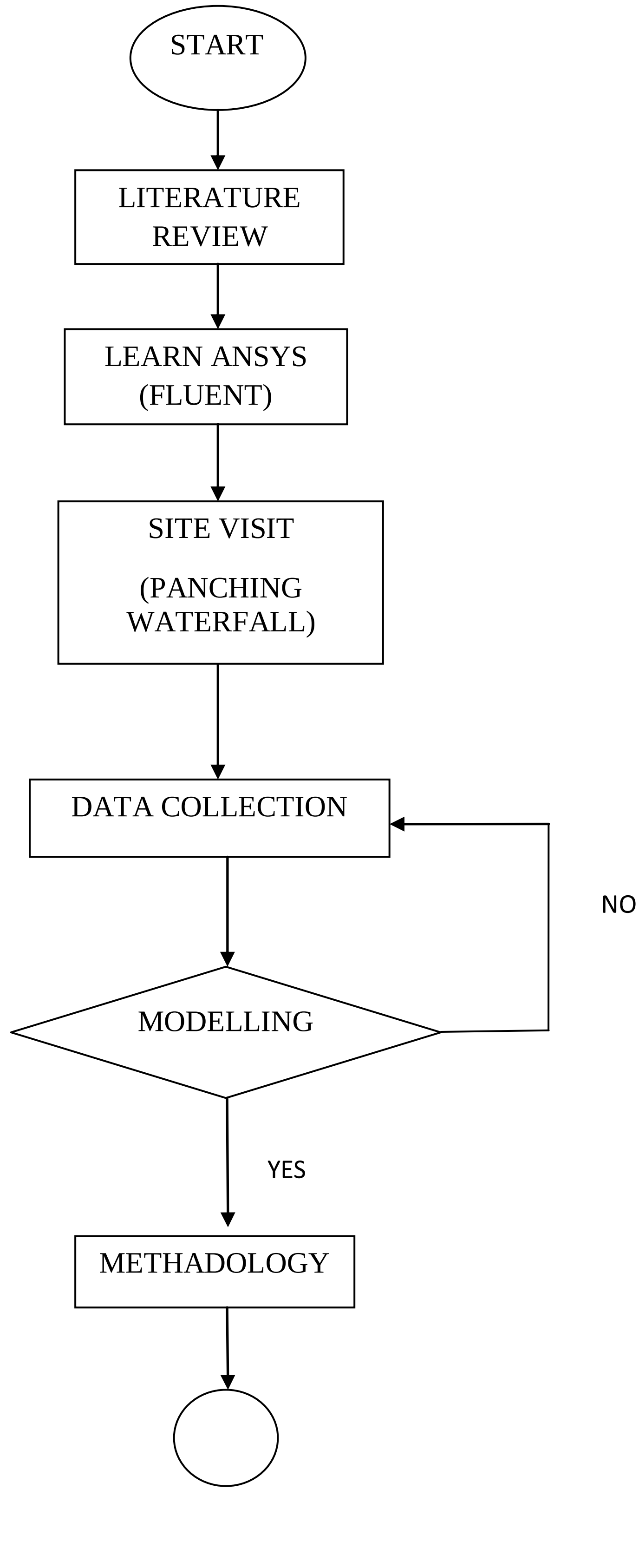


Figure 3.2: Micro Hydro Power System Illustration

The figure 3.3 above shows the illustration of micro hydro power. Water flow is channel to the turbine nozzle using a penstock. Water is collected in a dam type container or also known as forebay. Water flow through the penstock and when it impact with the turbine, turbine will rotate. Then the water will flow out of the turbine to the river.


START
LITERATURE REVIEW
LEARN ANSYS (FLUENT)
SITE VISIT
(PANCHING WATERFALL)
DATA COLLECTION
NO
MODELLING
YES
METHADOLOGY

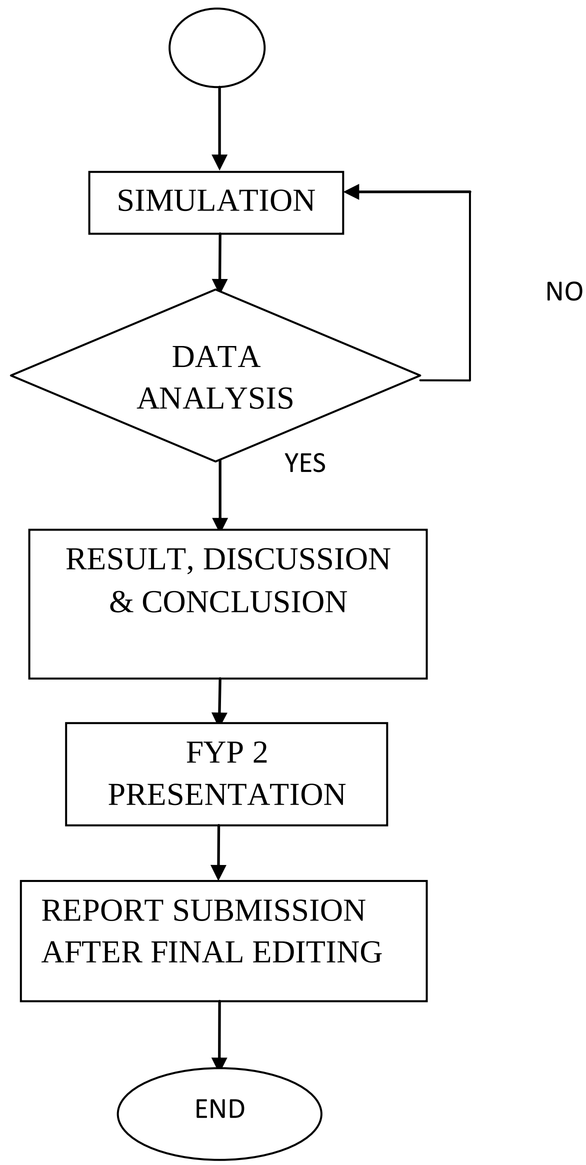


Figure 3.3: Overall Methodology Flow Chart

3.2 DESIGN FLOW CHART

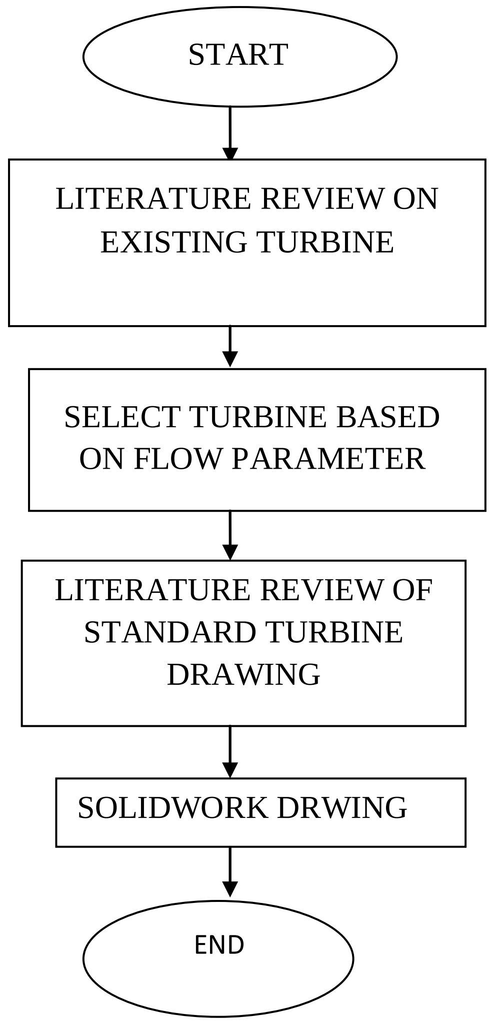


Figure 3.4: Design Flowchart

3.3 SIMULATION FLOW CHART

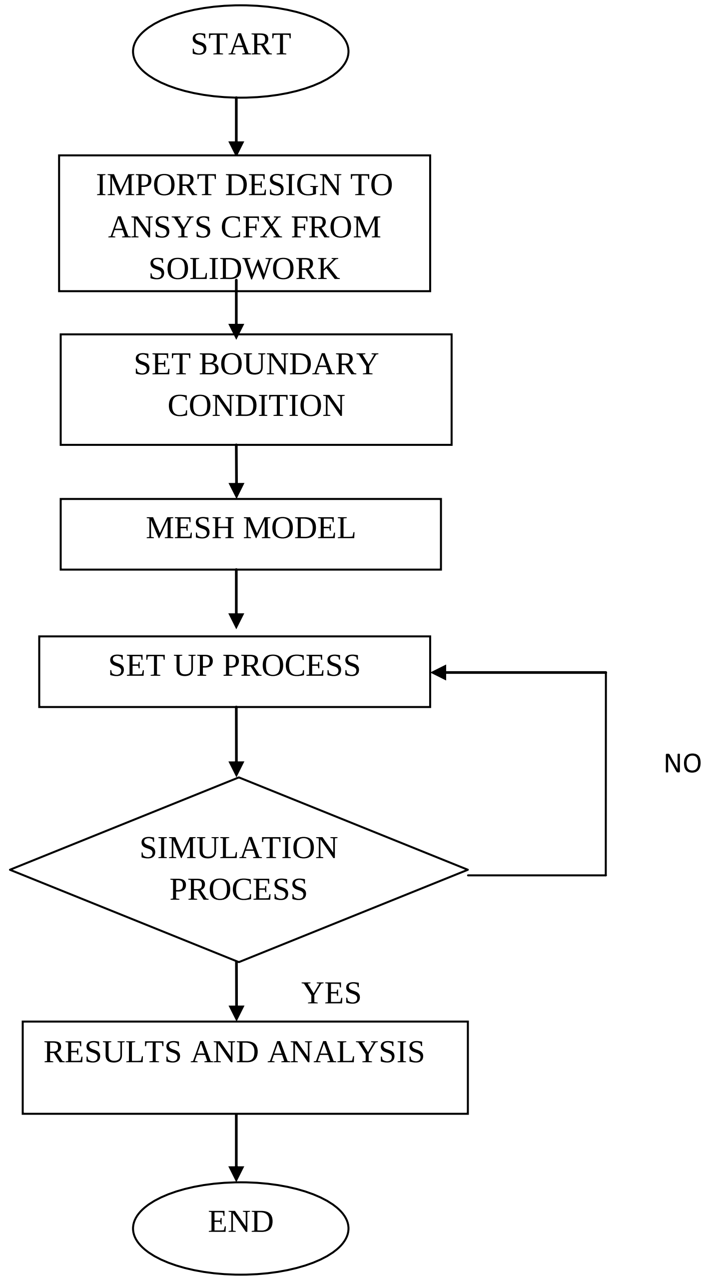


Figure 3.5: Simulation Flowchart

3.4 DESIGN OF TURBINE

Turbine is selected according to the value of Head (H) and the flow rate (m^3/s) of water. According to the turbine application chart in figure 3.7, with 100 m head and 0.02 m^3/s flow rate, Pelton and Turgo turbine are suitable to be used. These three types of turbine are suitable for high head flow.

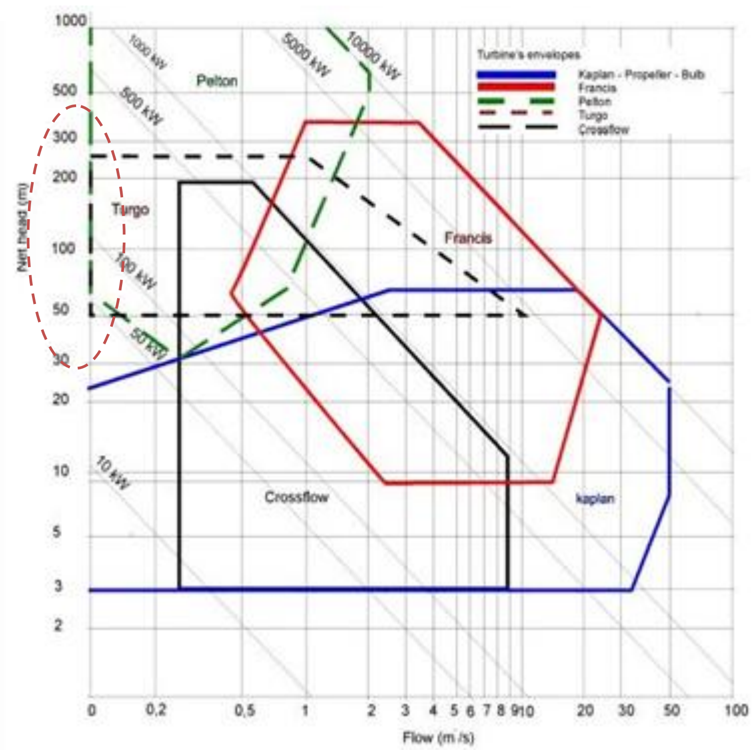


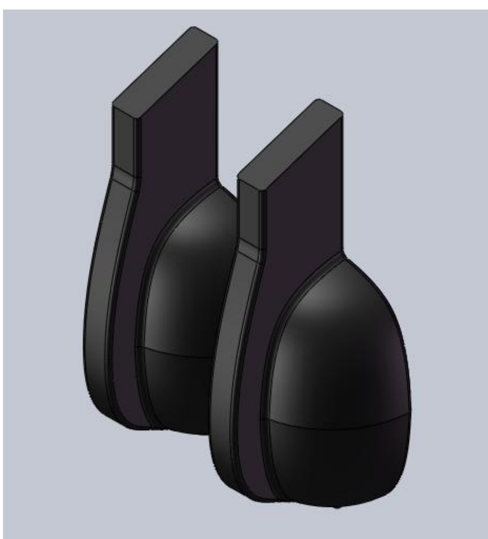
Figure 3.6: Turbine Selection Chart

Source: European Small Hydropower Association

3.4.1 Pelton Cup

Pelton turbine is decided to be used for micro hydro power simulation for river of high head. The following figures are the design of Pelton turbine in Solidwork 2012. Pelton cup is designed to increase the efficiency of the turbine. The dimension of the design is determined from existing micro hydro power. In order to get high efficiency, the size is suitable with the flow rate (Q) of water and Head (m) of waterfall.

Pelton cup has two parts which is symmetry as shown in figure 3.8. This is to direct water to the cup and force the cup to rotate to higher rpm. The rotation speed affects the output of the micro hydro power. So, the design is an important factor for Pelton cup turbine.



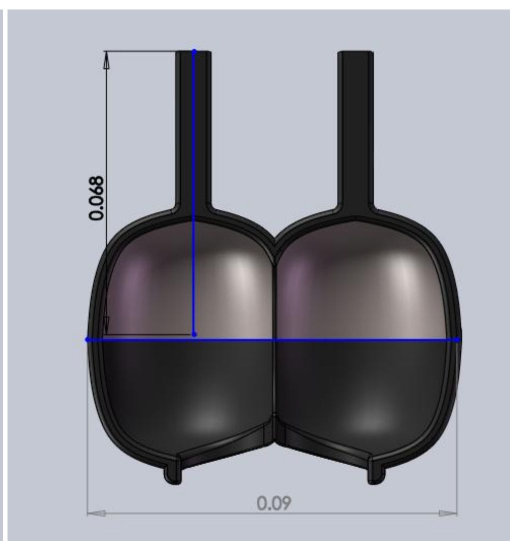


Figure 3.7: Pelton cup front view

3.4.2 Pelton Wheel Turbine

Pelton wheel turbine which is also known as Pelton runner is 0.5 meter maximum diameter. This is the standard of micro hydro power turbine. For higher head water flow, bigger size of diameter must be used in order to support the velocity of water flow but at the same time for micro hydro power, the turbine must have characteristics that can produce 100 kW power. Number of cup is 16 which is optimum number that suits the parameters of the flow of water.

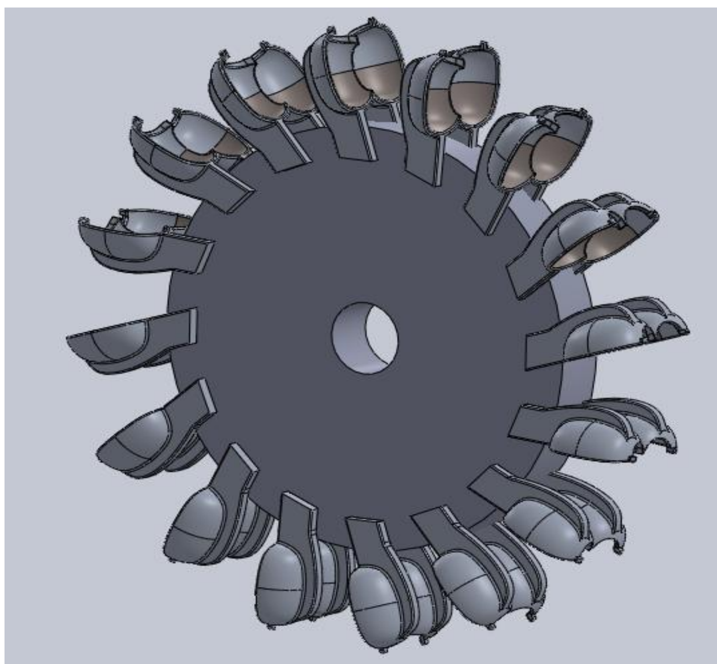


Figure 3.8: Pelton Wheel Turbine

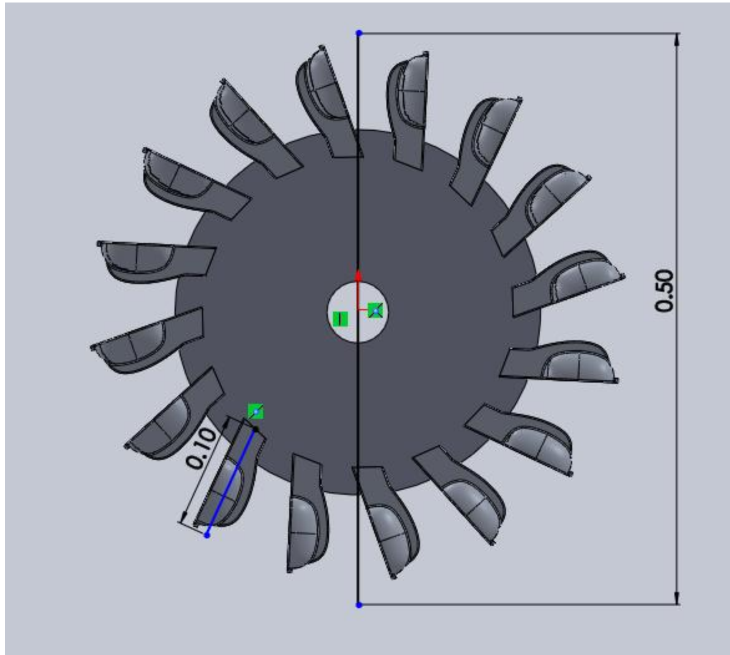


Figure 3.9: Drawing view of Pelton Turbine

Suitable diameter of nozzle is used for Micro Hydro Power. Water flows from the highest head to the turbine through PVC piping. The dimension usually ranges from 5 to 10 centimeters in diameter. It is determined from the head and pressure of water flow.

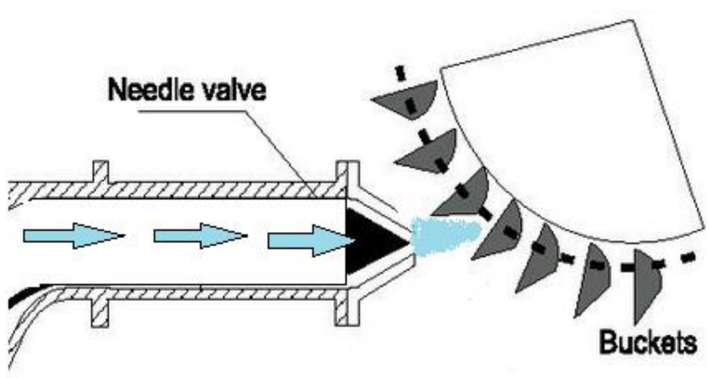


Figure 3.10: Water jet from nozzle

3.4.3 Turgo Turbine

Turgo turbine is suitable to be installed for medium to high head flow for micro hydro power. Turgo turbines are able to handle a higher flow rate than a physically similar-sized Pelton turbine. The size and material of the turbine 0.5 m diameter and the material is steel alloy with nickel. Constant speed and pressure of water jet is to apply to the turbine to rotate the turbine.

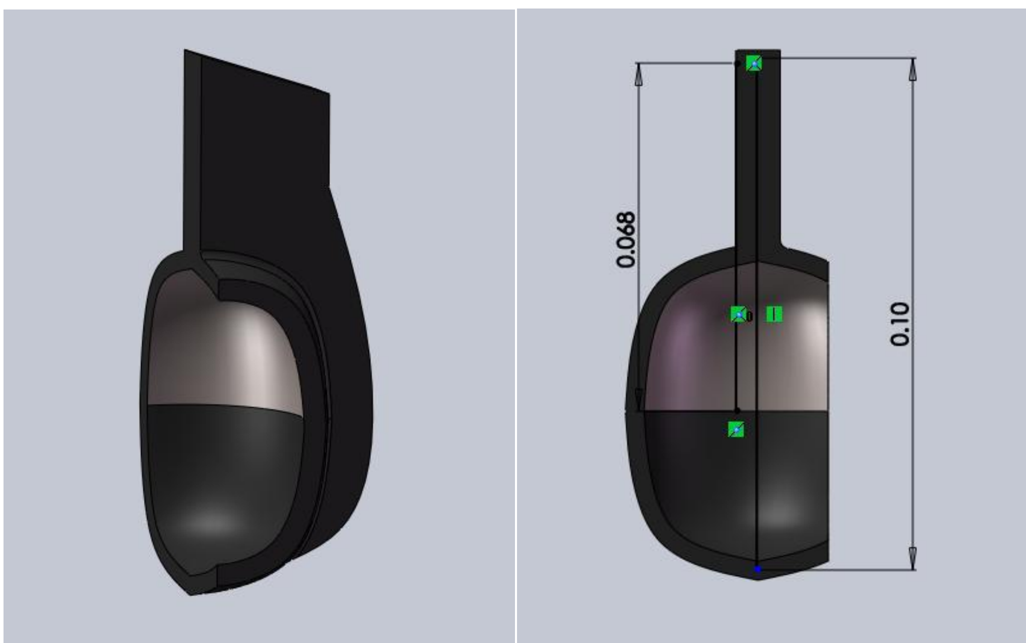


Figure 3.11: Turgo Cup design

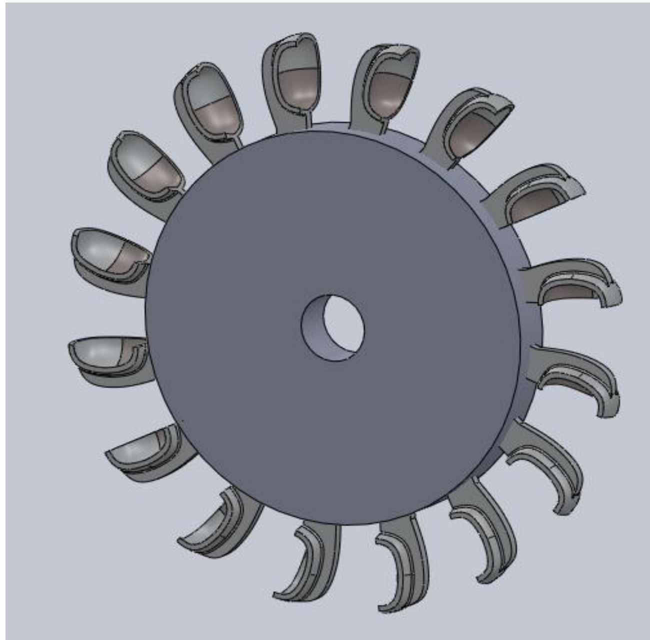


Figure 3.12: Turgo Turbine

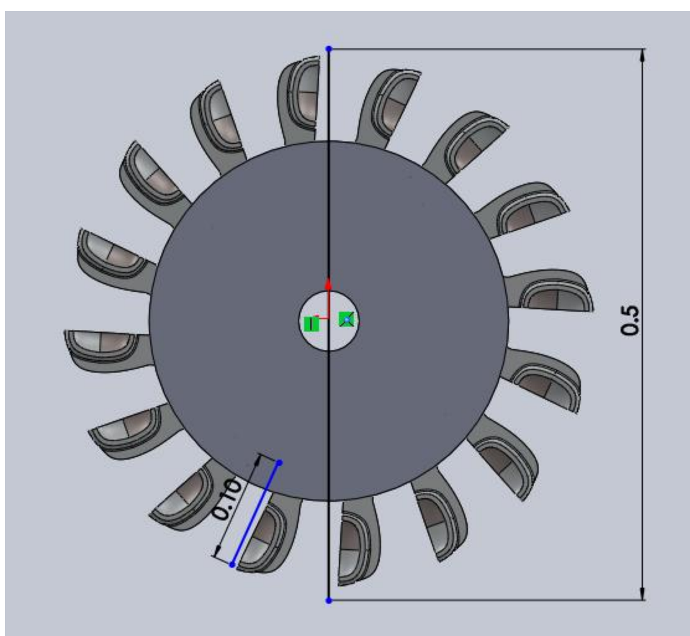


Figure 3.13: Turgo Turbine Dimension

3.5 MODELLING USING ANSYS CFX

ANSYS CFX software contains the broad physical modeling capabilities needed to model fluid flow. In this case, ANSYS CFX is used to simulate fluid flow and obtain the force of Micro Hydro Power turbine. The process of simulation begins with designing the turbine in Solidwork 2012. The design was then imported to ANSYS for further analysis. A complete workflow for one simulation is presented in this section. The process follows step by step according to the project schematic as shown in figure 3.15.

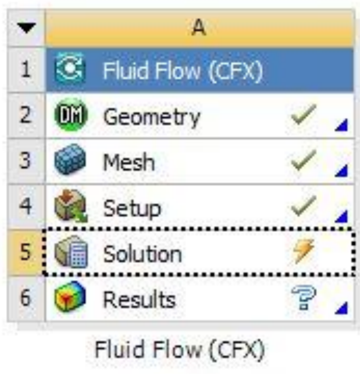


Figure 3.14: CFX Project Schematic

The tick sign at geometry defined that the geometry is ready to be meshed. Mesh generation is one of the most critical aspects of engineering simulation. A complicated drawing may take longer time to mesh and for the solver to run. On the other hand, a simple design may results in inaccuracy of the result obtain. For fluid dynamic simulation, high quality mesh is needed in both element and shape. The mesh is automatically loaded and displayed in the graphics window by default. When meshing process is completed, tick sign will appear at column B3 from the figure above. This means that the process can proceed to the next step which is setup.

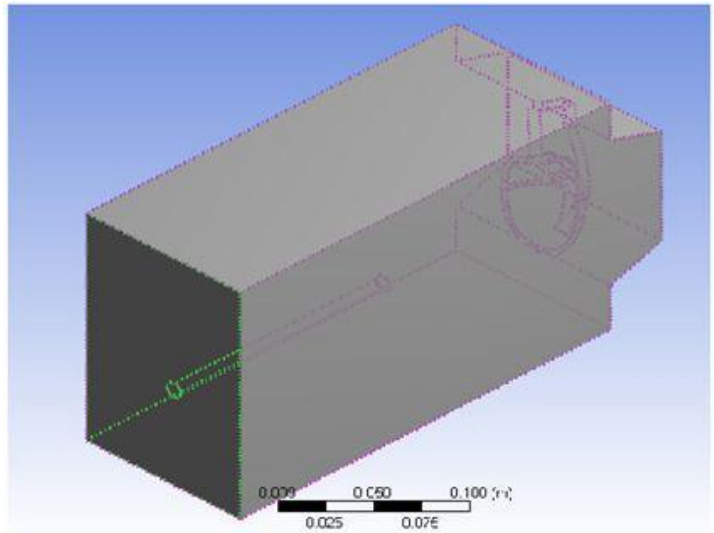


Figure 3.15: Boolean using Design Modeller

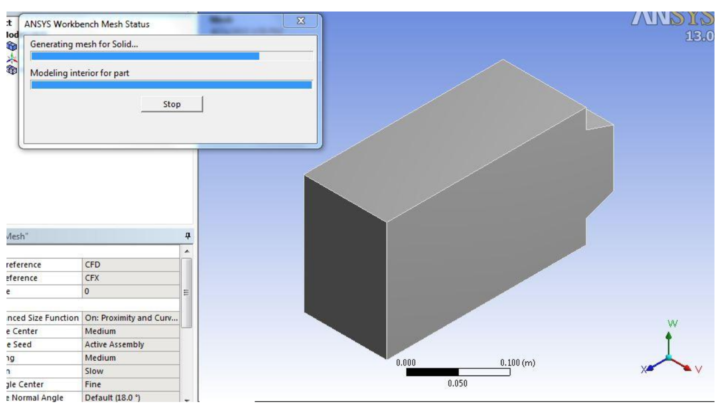


Figure 3.16: Generating Mesh in ANSYS CFX

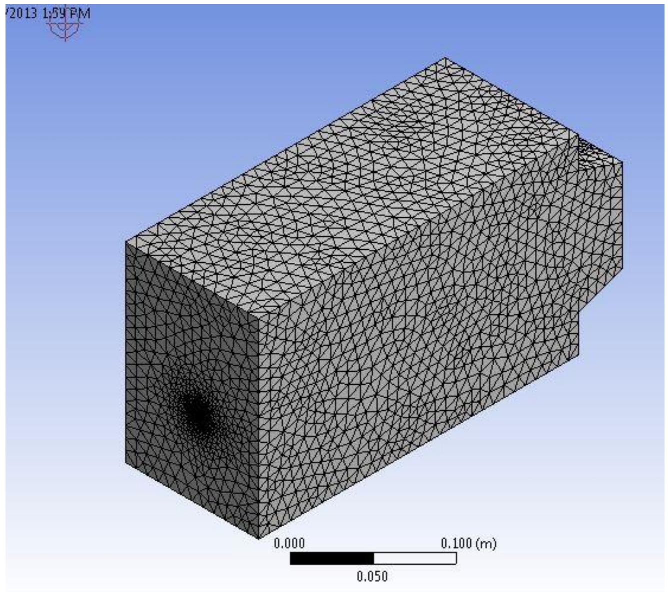


Figure 3.17: Completed Mesh

As shown in figure 3.18, the meshing of the fluid domain was done by defining the sizing and centre of relevance of the geometry. It takes some time to generate mesh depending on the design of the turbine. The meshing process takes place in every part of the assembly. ANSYS Meshing has a physics preference setting ensuring the right mesh for each simulation. The following step is to insert setup for input in the right side toolbar as shown in figure 3.17.

When the data input is inserted at the setup, ANSYS will generate the solution of the turbine and it may take some time. ANSYS meshing 14.0 does an excellent job meshing automatically without manual setting.

The next process is setup with ANSYS Pre. A detailed setup was defined here. In the Analysis Type section, steady state option was chosen.

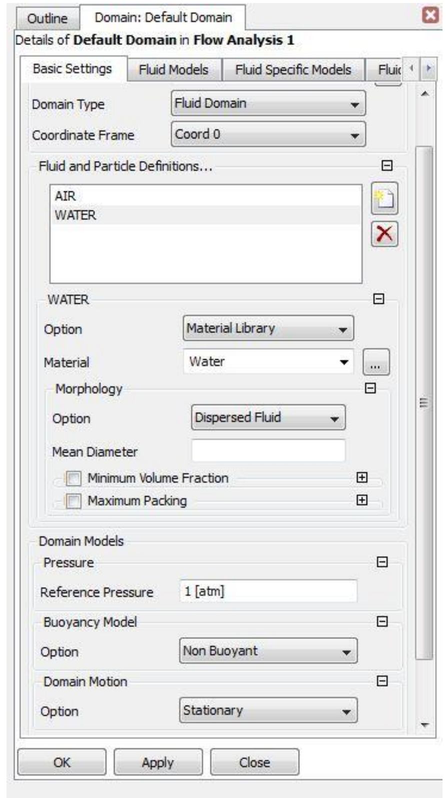


Figure 3.18: Setup Toolbar

Fluid properties for this simulation are water. The flow of water from the river to the turbine is applied to the analysis. So the properties of water are kept constant. The table above describes the general water properties which are estimated to be more or less the same value with river water.

The velocity of water is 62.5 m/s and average static pressure is zero. The volumetric fraction of air and water is set to 1 and 0.

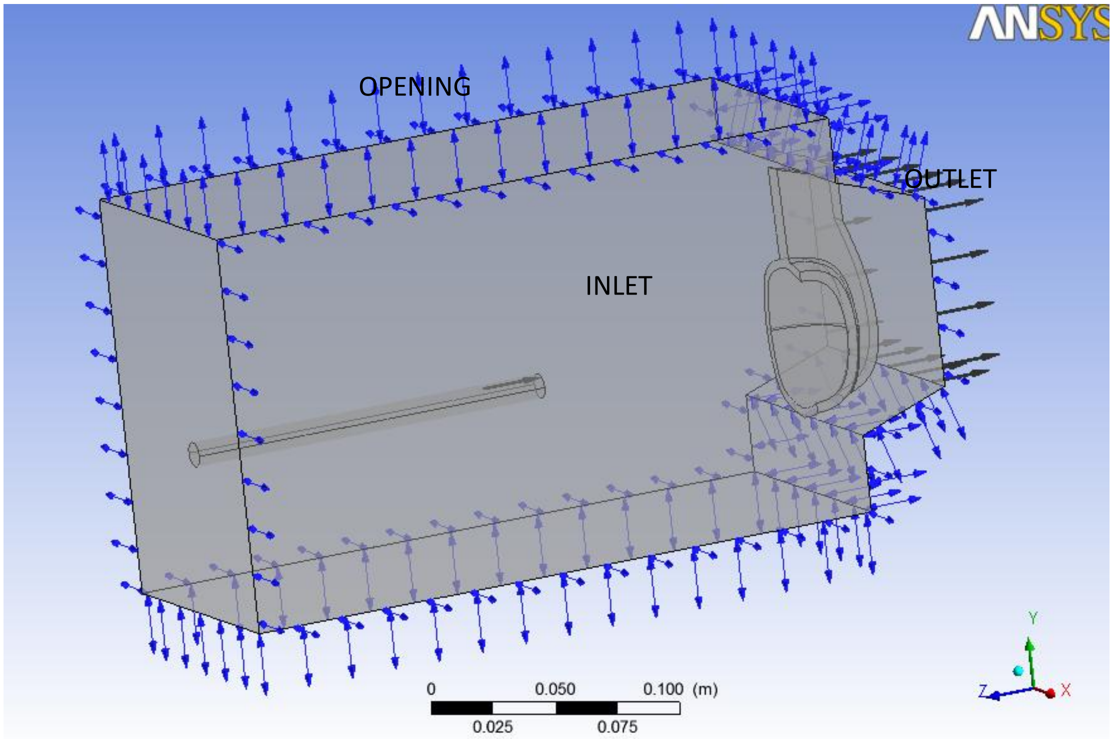


Figure 3.19: Set up boundary condition

Set up boundary condition is important to apply the limitation of the process. To set up boundary condition of a fluid flow, set additional boundary conditions at inlets, exits, and walls. The boundary condition in this case is set up to surrounding. However, it still had to be defined in order to make sure accurate result is performed.

Finally, run the result to collect the output data from ANSYS Fluent. This is to solve a three-dimensional turbulent fluid flow. There are various outputs that can be determined from the results. The flow of water through the turbine is shown in the results.

From the result obtain, analysis has to be done to determine the performance of hydropower to be used in Panching Waterfall. The value of force and torque can be determined from the analysis.

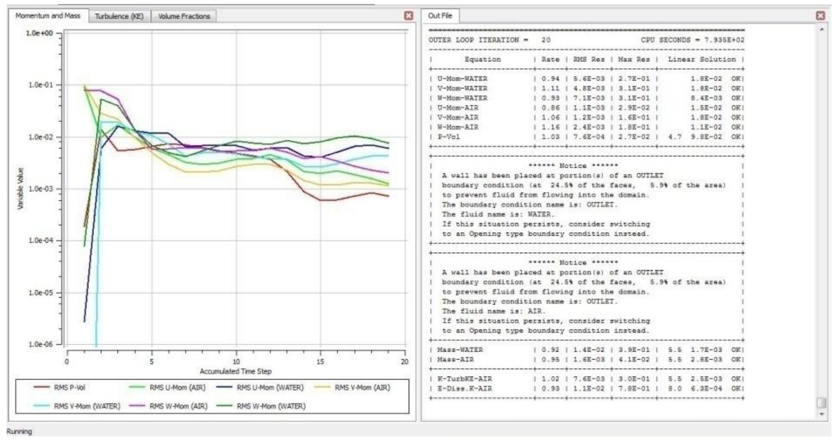


Figure 3.20: Generating Results

Solver control and the output is where the calculation of the solver takes part. The maximum number of iterations is set to 100 iterations. A start run button is clicked and the solver started. This calculation may take several minutes to be successfully completed.

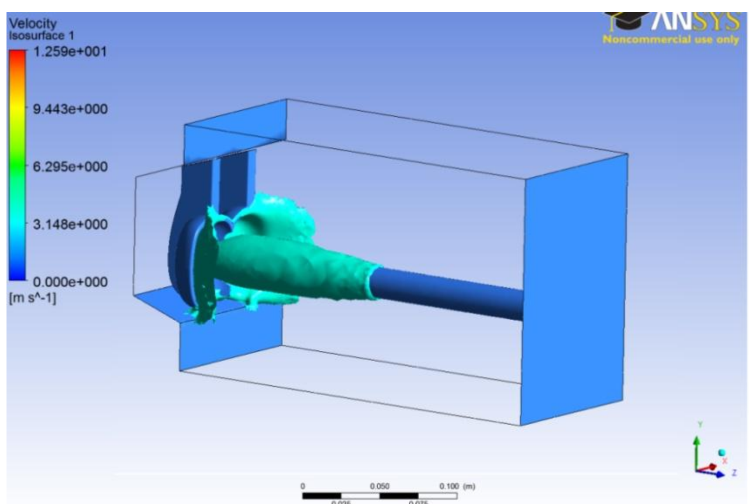


Figure 3.21: Complete Simulation

CHAPTER 4

RESULTS AND DISCUSSION

4.1 SIMULATION AND ANALYTICAL RESULTS

From the results obtain in ANSYS CFX, the parameters output for Pelton cup and Turgo cup are observed and tabulated. The visualization of the flow of water from high speed water jet to impact the Pelton and Turgo bucket are determined. The data obtained from the analysis are then compared to determine a suitable bucket to be used for high head river flow of 70 m.

The speed of water and dimension of both buckets are the same. The differences at the design and angle of water jet affect the value of force and torque of each bucket. On the other hand, the power output and efficiency of the turbine are also affected. The comparisons are made according to the data obtained from the simulations. In order to compare the results, the value of velocity inlet, size of turbine and diameter of water jet are kept constant.

All the simulations successfully produce the force applied, velocity and torque on the Pelton and Turgo cups. The cup is in a stationary condition where it is not rotating. The value of speed and mass flow rate is set due to the data collection earlier from site visit at

Panching Waterfall. The velocity of water is determined from mechanical energy balance in the next section.

Mechanical energy balance for impulse turbine

$$\frac{v_1^2}{2g} + \frac{P_1}{\rho} + z_1 = \frac{v_2^2}{2g} + \frac{P_2}{\rho} + z_2 + h_L$$

From the equation, simplification can be made by assuming the pressure at both ends is atmospheric, the initial velocity equals final velocity (conservation of mass) and h_f is equal to zero. So, the simplified equation is

$$z_1 = z_2 + h_L$$

$$h_L = z_1 - z_2$$

$$h_L = \frac{fL}{D}\frac{V^2}{2g}$$

The value of *f* is determined from Moody Chart which the value for turbulent flow of water is 0.02.

$$v^2 = 2\ (9.81)\ (0.01).\ \frac{1}{0.02(0.1)}$$

$$v = 9.9 \text{ m/s (round off to 10 m/s)}$$

And then, the value of nozzle velocity is determined from the following equation

$$d_N V_N = D_p V_p$$

$$V_N = \left(\frac{D_p}{d_N}\right) \times (10)$$

$$= \frac{0.01^2}{0.004^2} \text{ X } 10 = 62.5 \text{ m/s}$$

4.2 SIMULATION RESULTS FOR PELTON TURBINE

4.2.1 CFX Simulation Output

The visualization of water flow through the middle bucket is shown. The water jet is at the center of the Pelton cup act as a potential energy. The speed of water through the pipe is 10.18 m/s. The pipe has nozzle that act to enhance the velocity of water jet. The nozzle velocity is 62.5 m/s from the design of the Pelton cup itself, the flow is divided equally in order to produce no axial force on the turbine wheel.

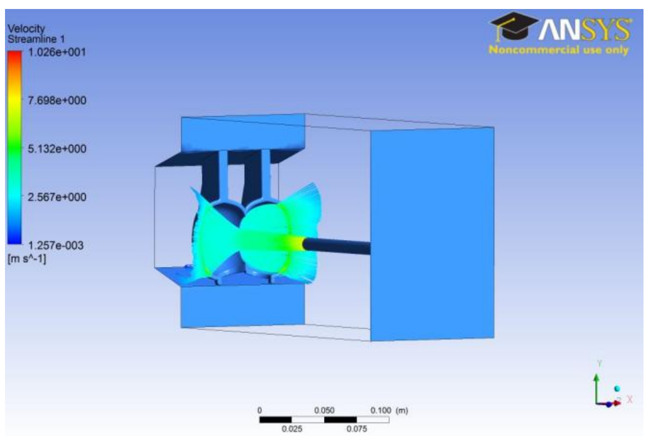


Figure 4.1: Velocity Streamline Visualization of Pelton

From the visualization in the figure 4.1, the water is deflected equally on each half of the cup by an angle. The angle is estimated from the visualization. The relative velocity ω_1 and ω_2 will be the same at the cup surface which is 25.67 m/s. However, at the instant that the water hit the cup surface, the velocity is 0 m/s and then it increases and water will reflect due to the surface condition of the cup. Due to this circumstance, the cup will experience the impact and tends to move on the force of kinetic energy.

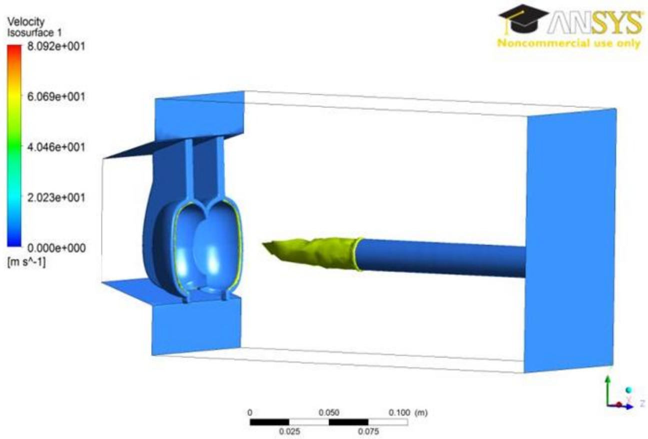


Figure 4.2 (a)

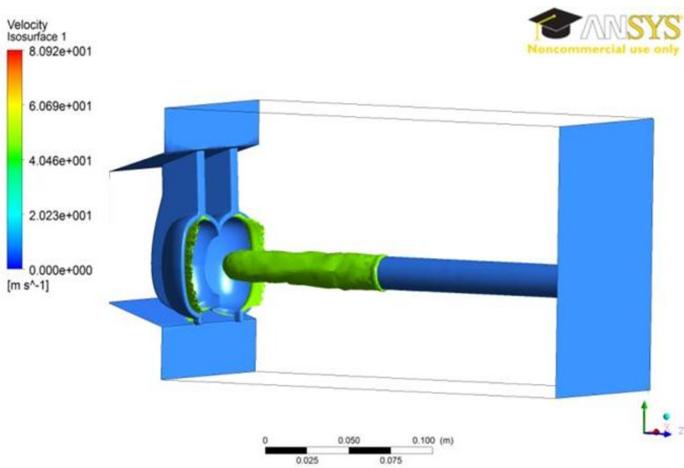


Figure 4.2 (b)

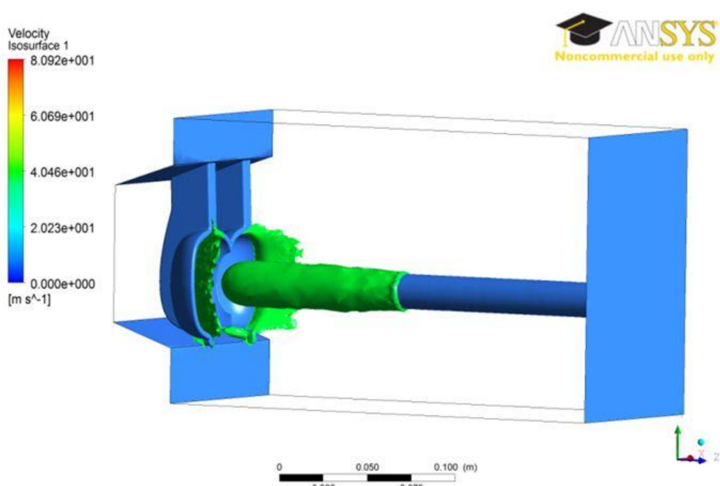


Figure 4.2 (c)

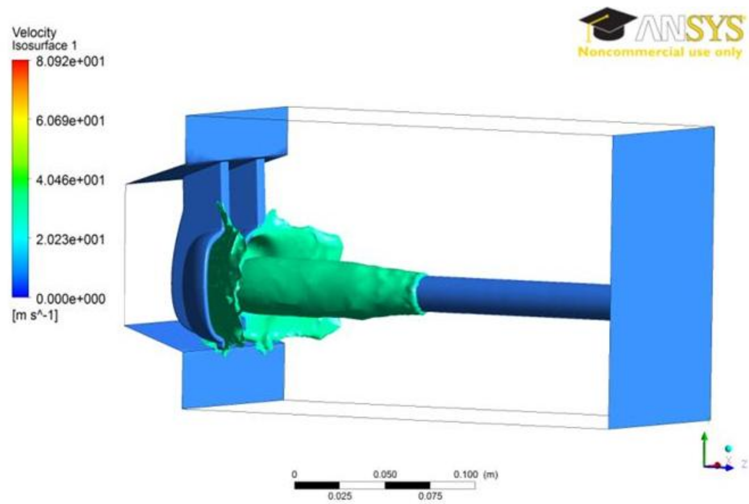


Figure 4.2 (d)

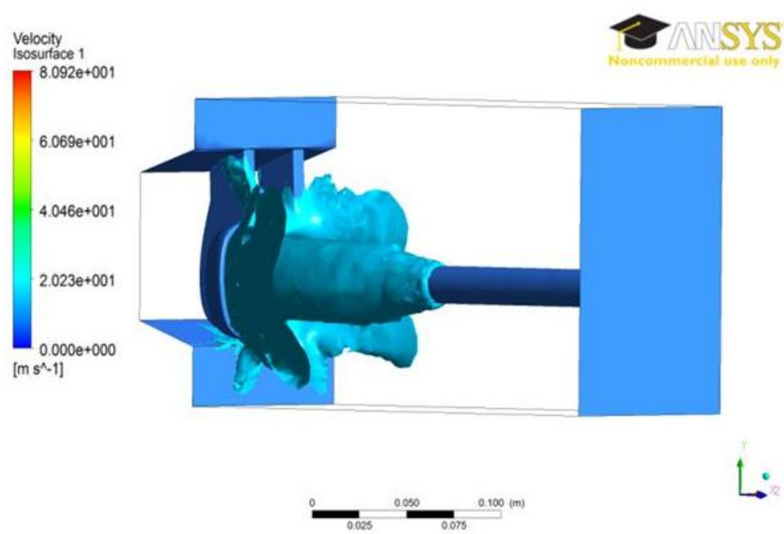


Figure 4.2 (e)

Figure 4.2 a, b, c, d, e and f show the effect of water flow sequence and its velocity. The images visualize the isosurface effects. Isosurface is a 3D surface representation of points with equal value in a 3D distribution. It is proven that when water impacts the cup, the velocity is 0 m/s. This is why there are no effects of simulation on the cup at this instant. The force of the water jet strikes on the bucket and transforms potential energy to kinetic energy.

The sequences show the different frames of water flow. Figure 4.2 a, b, c, d, and e show the speed of water at 70.5, 50.5, 30.5, 20.5, and 10 m/s respectively. From the data mention, the speed keeps reducing and when it hit the cup it will reduce its speed to 0m/s and then increase gradually and water was reflected according to the design of the cup. This pattern can be seen clearly from the velocity graph figure below.

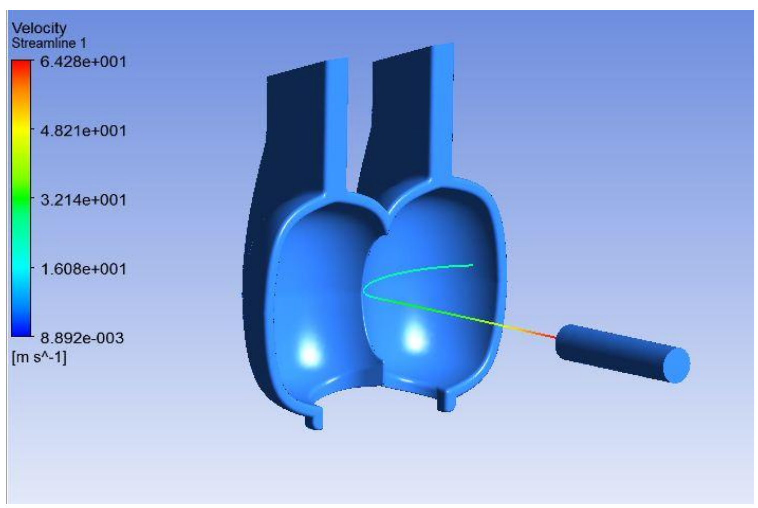


Figure 4.3: Velocity Streamline for Chart

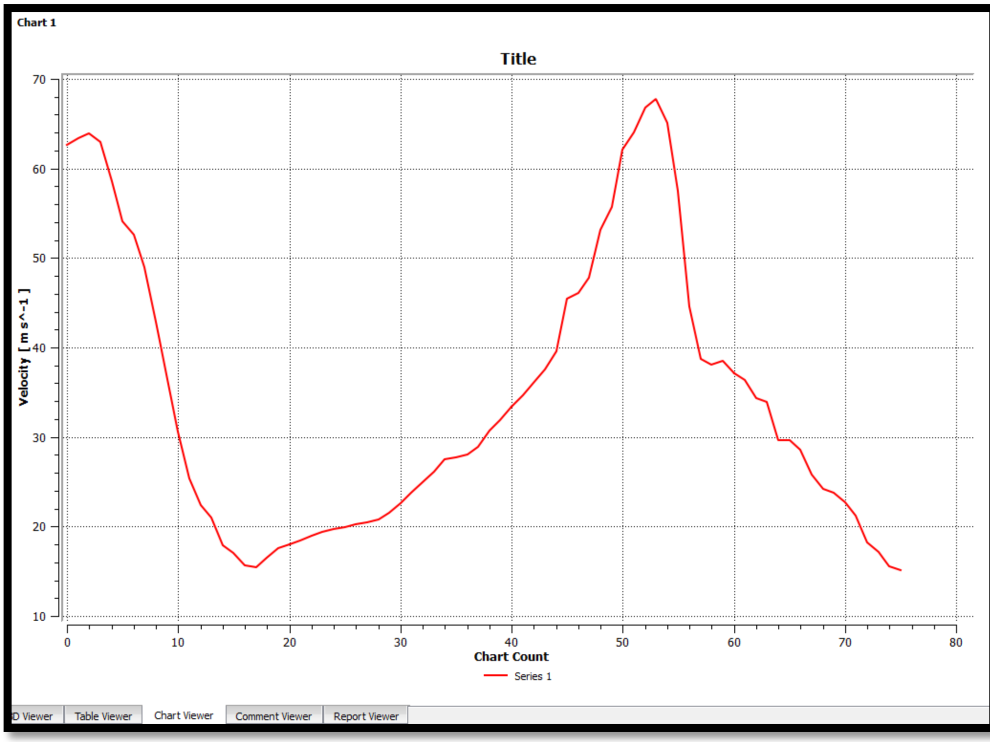


Figure 4.4: Velocity chart

Figure 4.4 shows the velocity graph of a Pelton cup. The chart is formed from one streamline as shown in figure 4.4. It shows the ups and downs of velocity when it hits the cup and reflected. From the graph, it can be concluded that the lowest velocity occur when the water hit and impact the cup.

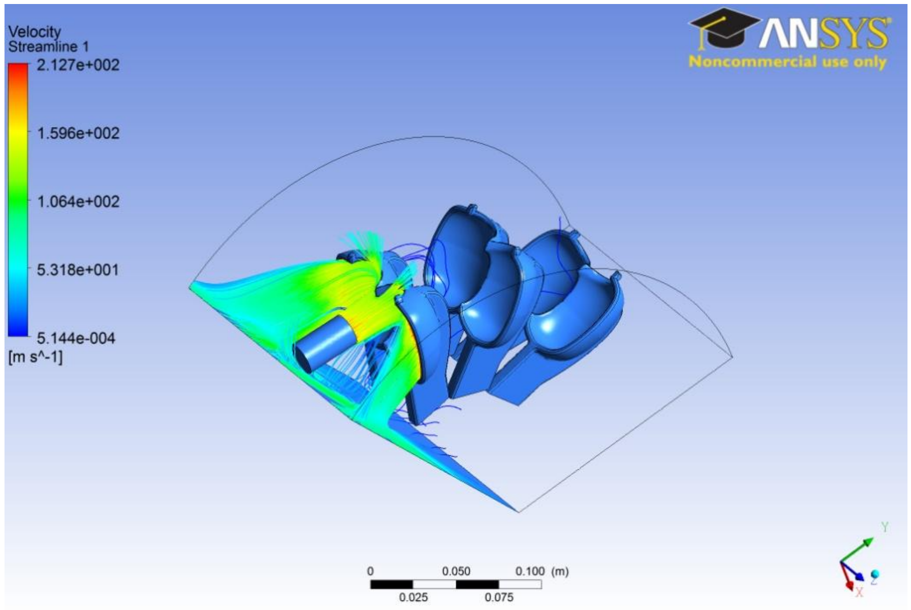


Figure 4.5: Simulation of part of turbine

Figure 4.6 illustrates the angle of a water jet to the turbine. The simulation is stationary; this is the reason that the flow does not involve the other cup. However, this image can give a general illustration of the turbine rotation. When the turbine rotates, water will impact each cup and turn the wheel. Usually, four water jets are used to optimize the rotation of the turbine. The friction loss of the pipe is neglected, so does the length of the pipe. If the cup moves towards the jet, the water gains speed, if it pushes a cup moving away, it loses speed.

The simulation output is presented in table and graph. Then, the value is compared to the calculation in order to validate the data.

4.2.2 Analysis on Pelton

Table 4.1: Pelton simulation results

Location	Type	x	y	z
Default Domain	Pressure Force	5.6076e+01	5.9310e-02	-4.8587e-01
	Viscous Force	-7.0989e-01	-3.4838e-02	4.7019e-03
	Total Force	5.1366e+01	2.4473e-02	-4.8117e-01
	Pressure Torque	-5.2229e-02	6.1953e+00	-5.0976e+00
	Viscous Torque	4.0985e-03	-7.8251e-02	6.0199e-02

Table 1 presented the simulation results for a Pelton cup. It shows the value of force and torque of the Pelton cup. The results are presented from x, y and z direction. In this case, the magnitude of velocity is calculated in the direstion of x, y and z is taken because the water flow in 3 Dimension and hit the Pelton cup in this direction. The magnitude of force from table 1 is 55.36 N.

From the simulation results, power output can be calculated by applying the value of force which are 55.36 N and multiply with the value of velocity

$$P = T\ \omega$$

$$P = F\ r\ \omega \text{ where } U = r\ \omega$$

$$P = F\ U = 51.36 \text{ X } 28.75$$

$$= \underline{\underline{1476.6 \text{ watt}}}$$

So, the power output for Pelton cup from the result extract from the simulation is 1.476 kW.

4.6The figure 4.7 shows the velocity diagram of water flow of Pelton cup. Velocity diagram is used to analyze the flow through the moving curved cup. The diagram shows the section through a bucket which is being acted on by a water jet. The plane of section is parallel to the axis of the wheel of the Pelton turbine.

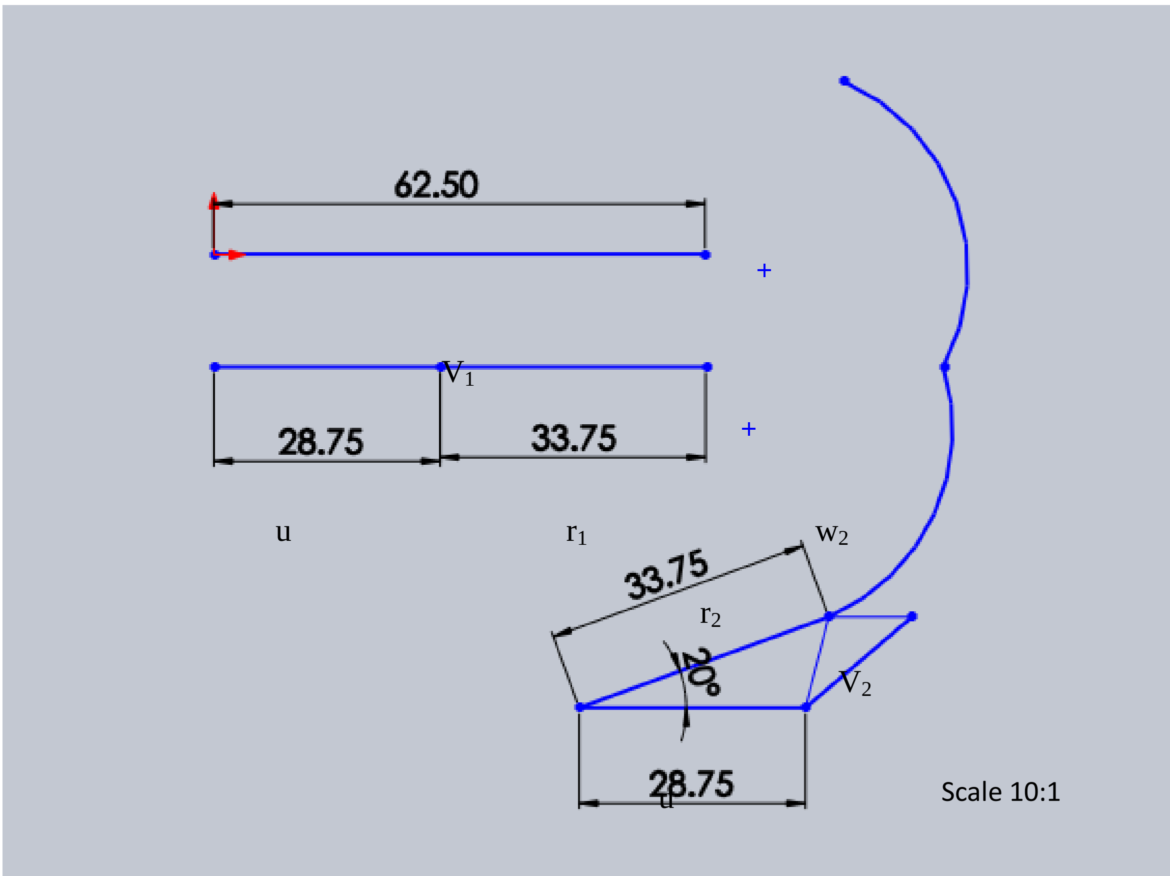


Figure 4.6: Vector Diagram of Pelton Cup

The variable k is determined, which gives the ratio between the peripheral velocity of the runner u and the linear velocity of the jet v_1 before the water hits the runner. The bucket speed u is often expressed as a fraction v_1 by the rational expression

$$\eta_H = \frac{v^2\left(k - k^2\right).(1 + \cos\ 20)}{gH}$$

Table 4.2: Value of velocity coefficient k related to efficiency η

k	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
η	0.177	0.316	0.415	0.47	0.49	0.47	0.42	0.316	0.177

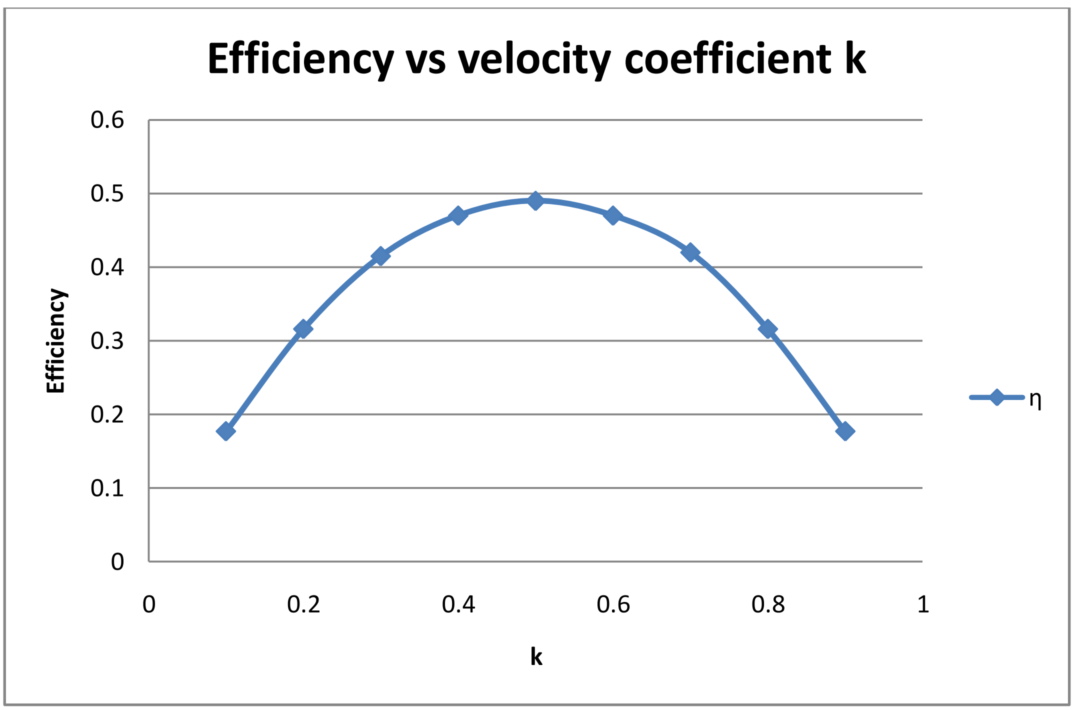


Figure 4.7: Efficiency versus k

From the graph above, the value of k is determined from the value of the maximum efficiency. The maximum efficiency is 0.49 where it is clearly shown that the value of k is 0.5.

The velocity at inlet $v_{1,}$ bucket velocity u, the velocity relative to the bucket at inlet $r_{1,}$ velocity relative to the bucket at outlet $r_{2,}$ tangential component at v_2 is w_2 can be determined from the velocity diagram and absolute velocity can be determined to be compared to simulation results. The exit angle of the velocity diagram is 160^o. This is because the bucket turns the water through 160^o, and the water leaving the cup may not hit the back of the following cup. If the water hit the back of the cup, it will reduce the performance of the turbine when it tends to move in opposite directions. The diagram drawn is to scale that the velocity represents the length. This kinematic diagram also visualizes the flow of water and it is identical to the simulation. The velocity of the bucket is 0.5 of the jet velocity.

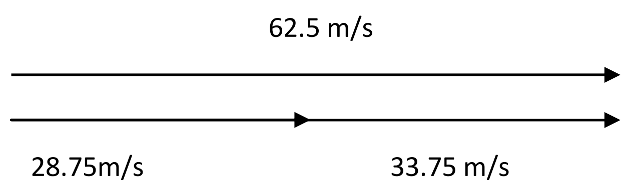


Figure 4.8: Velocity inlet diagram

From the velocity inlet diagram, velocity relative to the bucket at inlet r_1 can be determined which the value is 0.5 of the velocities at the inlet. It can be concluded that when tangential velocity r_1 is equal to 0, the torque is maximized, when r_1 is maximum, torque is equal to 0. However, in this case, consider that the velocity of buckets is 0.46 of the jet velocity as shown in figure 4.9.

4.2.3 Pelton Cup Calculations

The equation shows the value of the height of the penstock for Micro Hydro Power. In this case, the value of friction loss in the pipe is neglected. The speed of flow through the cup is 62.5 m/s.

i) Velocity of bucket

$U = k. V_1$

$= 0.46 \times 62.5$

$= 28.75$ m/s

ii) Velocity relative to bucket at inlet

$V_1 - U = r_1 = r_2$

$62.5 - 28.75 = 33.75$ m/s

iii) Tangential component of the velocity at exit

$w_2 = u - r_2 \cos 20^o$

$= 28.75 - 33.75 \cos 20^o$

$= -2.964$

iv) Mass flow rate if the jet diameter is 0.01 m^2

$\dot{m} = \rho VA$

$= (1000)(62.5)(\pi)(0.004)^2/4$

$= 0.7853$ kg/s

v) Power generated

$P = \dot{m} U (U - V)(1 - \cos \beta_2)$

$= 0.7853 (28.75) (28.75 - 62.5) (1 - \cos 160^o)$

= -1478 watt (negative sign shows that power is extracted from the fluid)

vi) Torque of Pelton

$= \dot{m} R (U - V)(1 - \cos\beta_2)$

$= 0.7853 (0.068) (28.57-62.5) (1- \cos 160^o)$

= -3.51 N.m

vii) Maximum power is when $U = \frac{V_1}{2}$

$= \frac{62.5}{2} = 31.25$ m/s

$\therefore$ The value of P_{max} = - 1487.5 kW

From the calculation, power generated for the Pelton cup is close to the simulation results. Next step is to calculate the efficiency of the bucket speed. The maximum theorethecial efficiency can be determined from the following equation where the optimal nozzle efficiency ϕ_n is 0.95, whereas, bucket efficiency ϕ_b is 0.9.

$$\eta_{max} = \frac{1}{2} . \phi^2_n.(1- \phi_b. \cos\beta_2)$$

$$= \frac{1}{2}(0.95^2)(1-0.9 \cos 160^o)$$

$$=0.83 \text{ @ } 83 \%$$

Hydraulic efficiency, $\eta_H = \frac{P_{out}}{\rho g H Q} = \frac{1478}{(9.81)(1000)(0.0078)(20)} = \frac{1478}{1530} \text{ X } 100\%$

= 0.965 @ 96.5 %

4.3 SIMULATION RESULTS OF TURGO CUP

4.3.1 CFX Simulation Output

Turgo cup has almost the same features as Pelton cup. The difference is can be observed in the design on the cup. Generally, Turgo cup is half of Pelton in shape. The structure of Turgo cup is simpler and cheaper than Pelton. Turgo turbine can handle flow with excellent efficiency in a very wide range, while using a small impeller. The speed of water flow through the cup is 62.5 m/s same as Pelton cup. This is to compare the efficiency between Pelton and Turgo.

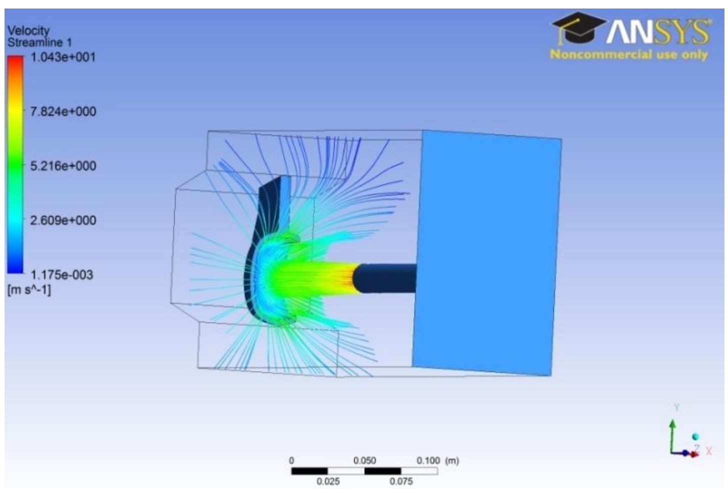


Figure 4.9: Turgo streamline simulation

From figure 4.10, it can be seen clearly that the water will reflect and discharge at the side of the cup. The high speed water jet is then directed on the turbine blades which deflect and reverse the flow. The discharged water is then transferred to the other cup and it will enhance the speed of rotation of the turbine. Initially, the speed is 62.5 m/s and it reduced gradually when it flows through the cup. It can be seen from the velocity streamline from figure above.

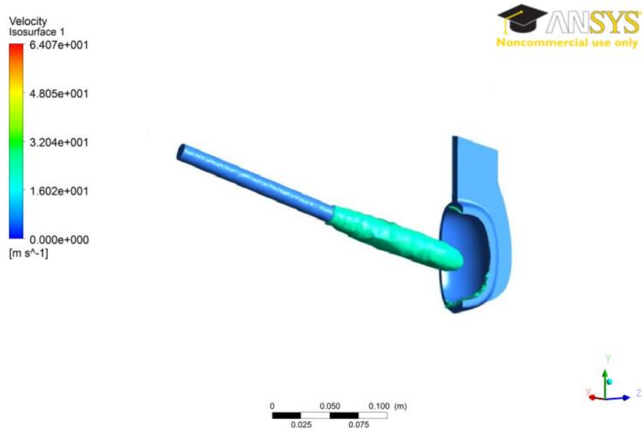


Figure 4.10 (a)

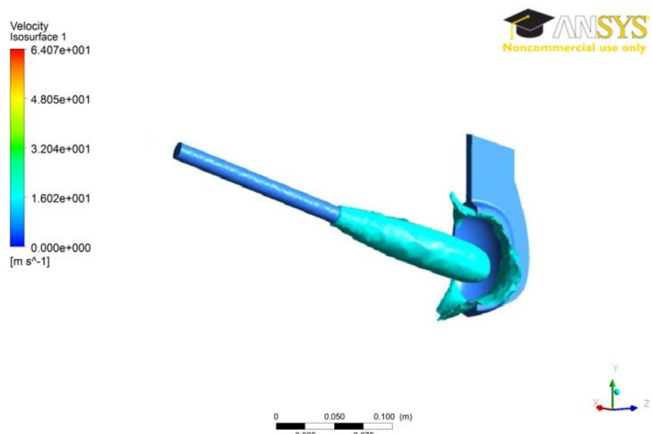


Figure 4.10 (b)

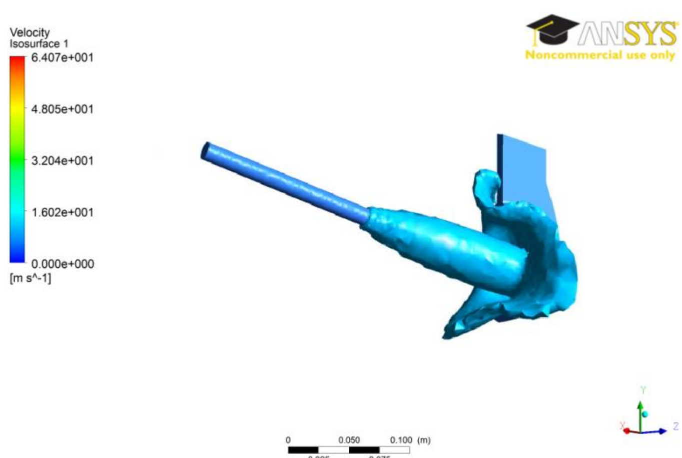


Figure 4.10 (c)

Figure 4.11 a, b, and c illustrates the flow of water through turbo cup at an angle of 20^o. When the water impacts the cup, it will split into two components and exits in two ways which are through the top and bottom of the cup as shown in figure 4.11 (d). The cup impact surface is tangential to the inner curve of the cup. The figures show the isosurface where the velocity can be seen from the simulation. The velocity reduces and the energy transferred to the cup and it reflects the water in the way of the Turgo cup design.

Table 4.3: Turgo Simulation Results

Location	Type	x	y	z
Default Domain	Pressure Force	4.8532e+01	1.5364e+00	-6.1242e-00
	Viscous Force	-4.8385e-01	-2.9036e-02	4.1372e-03
	Total Force	4.8048e+01	1.5074e+00	-6.0828e+00
	Pressure Torque	-7.1203e-01	6.0469e+00	-4.3440e+00
	Viscous Torque	6.5052e-03	-5.5743e-02	-4.3056e-02

Table 3 shows Turgo simulation results, the magnitude of force is 48.44 N.m. This value is smaller compared to Pelton cup. This force is determined from the default domain which is the Turgo cup. The force acting on Turgo cup has smaller value than Pelton.

P= F U

= 48.44 x 30.25

= 1465.5 watt

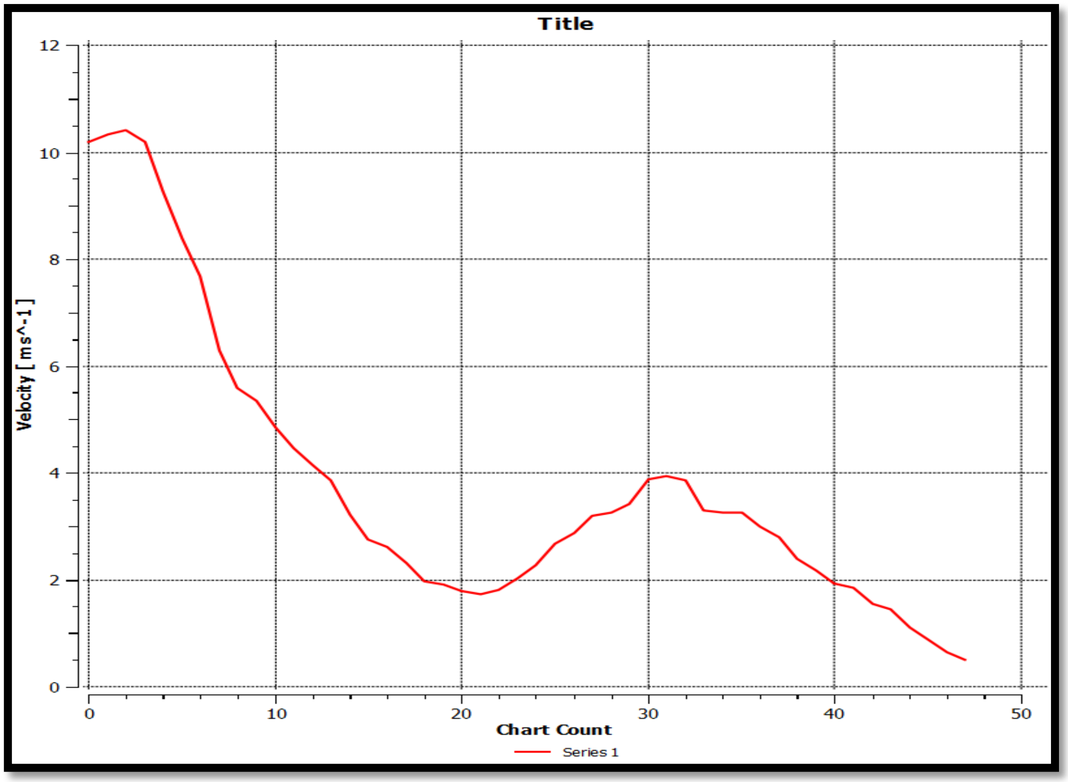
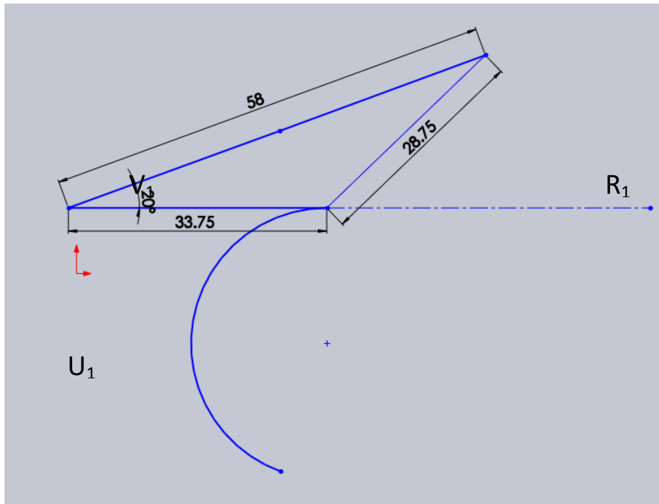


Figure 4.11: Velocity chart of Turgo

Figure 4.12 shows the velocity of water acting on the Turgo cup. The speed decrease and then increase a bit and reduce after the impact. The velocity pattern is more or less the same as Pelton. However, the range of shifting the value is different. At 1.8 m/s, the water impacts the cup and then reflects to be discharged. At this instant, the velocity increase until 3.9 m/s and then reduces again. This impact produces potential energy and it is transfer to kinetic energy.

4.3.2 Analysis on Turgo



Scale 10:1

Figure 4.12: Velocity Triangle of Turgo

The velocity diagram in figure 4.13 shows the V_1 is the absolute velocity, R_1 relative velocity and U_1 is relative tangential velocity. The diagram is drawn according to scale and the measurement represents the velocity of the water. From the velocity diagram, the value of absolute velocity can be determined. The absolute velocity is 8.9 m/s. Figure 4.14 shows the velocity outlet diagram.

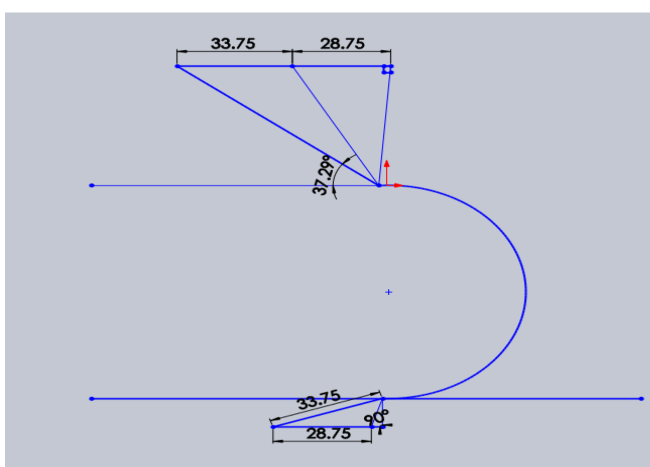


Figure 4.13: Velocity Outlet Diagram of Turgo

4.3.3 Turgo Cup Calculations

Turgo cup is an impulse turbine which has the same characteristics as Pelton cup. The calculation has the same concept. The differences can be seen from the design of the cup and the direction of water jet at the cup. So, in this case, the calculation is also the same where it applies the concept of impulse turbine. The value of torque is different and can be compared by calculating the efficiency. The peak efficiency point for Turgo turbine should occur at k= 0.53. From table 2, the efficiency is 0.484 calculated by interpolation.

i) Bucket speed of velocity

$U = 0.484.\sqrt{2gH}$

$= 0.484 \times 62.5$

$= 30.25$ m/s

ii) Velocity relative to bucket at inlet

$V_1 - U = r_1 = r_2$

$62.5 - 30.25 = 32.25$ m/s

iii) Tangential component of the velocity at exit

$w_2 = u - r_2 \cos 20^o$

$= 30.25 - 32.25 \cos 20^o$

$= -2$ m/s

iv) Mass flow rate if the jet diameter is 0.01 m^2

$\dot{m} = \rho VA$

$= (1000)(62.5)(\pi)(0.004)^2/4$

$= 0.7853$ kg/s

v) Power generated

$P = \dot{m} U(U - V)(1 - \cos \beta_2)$

$= 0.7853\ (30.25)\ (30.25 - 62.5)\ (1 - \cos 160^o)$

= -1483.5 watt (negative sign shows that power is extracted from the fluid)

vi) Torque of Turgo

$= \dot{m} R\ (U - V)\ (1 - \cos \beta_2)$

$= 0.7853\ (0.02)\ (30.25 - 62.5)\ (1 - \cos 160^o)$

= -0.98 N.m

vii) Hydraulic efficiency, $\eta_H = \dfrac{P_{out}}{\rho g H Q} = \dfrac{1483.5}{(9.81)(20)(7.8)} = \dfrac{1483.5}{1530.3} \text{ X } 100\%$

= 0.969 @ 96.9 %

4.4 COMPARISON BETWEEN PELTON AND TURGO

4.4.1 Simulation Results Output

Table 4.4: Simulation Output

Turbine Bucket	Force (N)	Torque (N.m)	Power (watt)
Pelton	55.36	9.25	1476.6
Turgo	48.44	7.41	1465.5

Table 4.5: Theoretical Results

Turbine Bucket	Bucket speed (U)	Torque (N.m)	Power (watt)
Pelton	28.75	3.51	1487.5
Turgo	30.25	0.98	1483.5

Table 4.4 and 4.5 shows the overall results of simulation and theoretical respectively. Generally, the power of Pelton is higher than Turgo because the value of torque is higher for Pelton in both methods. The differences of power output between Pelton and Turgo is very small. However, Pelton cup has higher efficiency. So, Pelton is the best turbine to be installed in Panching Waterfall.

Comparison can be made from 2 parts which are the simulation results and calculation. The value of percent error for this method is calculated. From the simulation, the value of Power for Pelton is 1591.6 Watt while power acting on Turgo is 1465.5 watt.

On the other hand, the value of power from calculation of Pelton is 1487 N.m while Turgo is 1483.5 watt.

$$\% \text{ Error} = \frac{\text{Therothetical value} - \text{Experimental value}}{\text{Theoretical val ;ue}} \text{ x } 100\%$$

$$\% \text{ Error for Pelton} = \frac{1487.5 - 1476.6}{1487.5} \text{ x } 100$$

$$= 0.069 \text{ @ } 6.9\%$$

$$\% \text{ Error for Turgo} = \frac{1483.5 - 1465.5}{1483.5} \text{ x } 100\%$$

$$= 0.012 \text{ @ } 1.2\%$$

The percent error indicates the percentage difference between calculation and simulation results. In this case the percent error is slightly high because the value of simulation results may have error at meshing size cell.

From the calculation that had been done, the power of Pelton is higher than Turgo. So Pelton turbine is more suitable to be used in Micro Hydro Power implementation at Panching Waterfall. The efficiency of Pelton cup according to the calculation is 0.965 while the efficiency of Turgo is 0.969. This small difference may affect the performance of the turbine.

CHAPTER 5

RECOMMENDATIONS AND CONCLUSIONS

Micro hydro power is very reliable to be applied in Panching Waterfall for electrification. From the comparison between Pelton Turbine and Turgo Turbine, Pelton Turbine shows higher efficiency than Turgo Turbine. Although Turgo is well known as high efficiency turbine, but in Panching Waterfall, the speed of water and height of waterfall affects the power output and the efficiency of the turbine. In order to install the suitable turbine at the site, proper equipment selection and installation are important to achieve optimum efficiency and power output.

For impulse turbine such as Pelton and Turgo with suitable speed coefficient around 0.5 is suitable for energy transfer from the water jet to the cup. Many improvements can be made to the development of turbine to increase the efficiency and effectiveness of the turbine. Technology transfer of appropriate turbines to local manufacturers can improve the turbine performance.

It can be concluded that, Pelton turbine is more suitable to be implemented in high head flow where the power output is 1476.6 watt compared to Turgo turbine which the power is 1465.5 watt.

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